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TRANSLATIONS FROM *BOL'SHAYA MEDITSINSKAYA ENTSIKLOPEDIYA*

[Following is a translation of selected articles from the Russian-Language Encyclopedia *Bol'shaya Meditsinskaya Entsiklopediya* (Great Medical Encyclopedia) by various authors, Vol 27, Moscow, Columns 699-710; 710-715; 715-717; 717-721; 770-789; 789-793; 793-798; 799-807; 807-817; 818-820; 820-821; 821-824.]

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Radiation Genetics

Radiation genetics is a science which studies the rules and regulations of the effect of radiation (ionizing radiation, ultraviolet rays and others) on the heredity of man, animals, plants, microorganisms and viruses. The origin of radiation genetics is associated with the publication of work by R. A. Nadson and G. S. Filippov (1925), who showed that ionizing radiations are the causes of mutations in fungi as well as with the publication of results of H. J. Muller's studies (1927) on drosophila and studies of L. Stadler (1928) on corn.

In connection with the extensive utilization of atomic energy in human life and particularly in conjunction with the study of space, in which the cosmonaut and living organisms associated with him are subjected to the effect of cosmic rays, problems of radiation genetics have acquired particularly great current importance, and radiation genetics has been converted into a rapidly developing branch of science. Studies on radiation genetics have been developed both abroad and in the Soviet Union. Problems of radiation genetics are being successfully solved in the USSR in the laboratories of Radiation Genetics of the Institute of Biophysics of the Academy of Sciences USSR, the Institute of Cytology and Genetics of the Siberian Department of the Academy of Sciences USSR, in the Radiobiology Department of the Institute of Atomic Energy imeni I. V. Kurchatov, in the Laboratory of Radiation Genetics of the Institute of Experimental Pathology and Therapy of the Academy of Medical Sciences USSR, and in the Institute of Radiation and Physico-Chemical Biology of the Academy of Sciences USSR.

Abroad, detailed studies are being conducted at the Oak Ridge Atomic Center, the Laboratories of the University of Illinois and Columbia University in the United States, at the Harwell Atomic Center in Great Britain, and in the Canadian Atomic Center (Chalk River Limited), the Radiobiology Laboratories of the Atomic Energy Commission of France, University of Lund (Holland) [there is a University of Leyden in Holland and a University of Lund in Sweden, but apparently there is no University of Lund in Holland], and in the Laboratory of Genetics of the Institute of Crops in Hathersleben (GDR) and others.

The main problems of radiation genetics are the following: 1) evaluation of the genetic effect caused by increase in the radiation background in man's environment

and the creation of effective measures for protecting human heredity against the injurious effect of radiation; 2) evaluation and prevention of the genetic effects of cosmic radiation; 3) the development of new methods of controlling the heredity of plants, animals, microorganisms and viruses for the creation of the necessary forms for man; 4) determination of the nature and magnitude of the genetic effect of radiation on all organic forms on the earth with the aim of controlling evolutionary processes of the entire biosphere in the event of an increase in the radiation background.

The effect of radiation on heredity is realized through the interaction of radiation energy with the matter making up the hereditary structures. This interaction is realized against the background of all metabolic processes carried out in the cell. The main hereditary structures of the cell are the chromosomes, which are in the cell nucleus. Heredity is recorded in the form of genetic information in molecules of deoxyribonucleic acid (q.v.) (DNA), which are included in the chromosomes together with protein. The body of each chromosome is differentiated along its length into separate specific loci, which have been given the name of genes. According to current concepts, the specificity of each of the genes is conditioned by the interrelationship of four nitrogen bases--thymine, guanine, cytosine and adenine, which are included in the DNA molecules. Therefore, in a chemical respect change in the hereditary structures under the influence of radiation, primarily is associated with the effect of radiation energy on the molecular structure of DNA.

The main categories of genetic effects of radiation are genic mutations, structural rearrangements of the loci, chromosomal rearrangements and nondisjunction of chromosomes. Genic mutations are associated with a change in the chemical structure in a microsection of the chromosome. Structural rearrangements in the chromosome locus are often about the size of several genes. Therefore, it is frequently impossible in practice to distinguish genic mutations from structural micromutations, and they are combined under the term "point mutations." Chromosome breaks and the formation of free fragments precede the occurrence of chromosome rearrangements. In the event of a combination of the fragments in the original order a recovery of the old structures occurs. In the case of recombination of fragments formed from the breaks new combinations of gene (fragment) sections occur in the form of chromosomal rearrangements. In the event of a disorder of meiosis (q.v.) nondisjunction of paired

(homologous) chromosomes is observed, in which individuals occur with extra or insufficient numbers of individual chromosomes. In man the number of chromosomes is equal to 46; nondisjunction leads to the birth of children with 47, 45 or other numbers of chromosomes. All these mutational changes in hereditary structures in man lead to disorders of developmental processes manifested in the form of different pathological processes. These pathological processes, transmitted to subsequent generations through sex cells carrying abnormalities in the chromosome structure, are called "hereditary diseases." If individuals contain mutations in one of the paired homologous chromosomes and thereby show abnormal characters, these mutations are called "dominant." If the heterozygote does not show mutational characters, the mutation is called "recessive" (see mutation). In man sex is determined by the existence of a pair of particular, so-called sex chromosomes: --XX--the female set of sex chromosomes and XY, the male set (see Sex). The other chromosomes are called "autosomes." The nature of inheritance of characters conditioned by genes of the sex chromosomes and genes of the autosomes is different. Therefore, both an inheritance of sex-linked characters and inheritance of the autosomal type occurs. An analysis of hereditary structures is largely accomplished by comprehensive study of the course of inheritance of characters from generation to generation and by following the changes in the chromosome structures by means of cytologic methods. Comprehensive analysis constitutes the basis of cytogenetics, a science which includes methods of cytology and genetics. Radiation causes a multitude of hereditary abnormalities when embryonic cells of organisms are irradiated. The use of radiation for the selection of microorganisms and plants is based on this. This new application of radiation has been given the name of "radiation selection."

The capacity of changing the heredity of organisms is primarily characteristic of penetrating radiation with high energy (corpuscular and electromagnetic). Low-energy photon radiation (ultraviolet rays, visible light), in the event of their penetration into the cell, also causes cytogenetic changes in it. The energy of ionizing radiation (see alpha-rays, beta-rays, gamma-rays, ionizing radiation, neutron radiation, x-rays), when absorbed by atoms and molecules of matter, cause ionization and excitation of them. Ultraviolet rays and visible light are absorbed by cell substances differently, depending on their molecular configuration, and produce signs of excitation in them.

The main problem of radiation genetics is a study of

the effect of ionizing radiation on human heredity. Numerous studies in the field of radiation genetics can be divided into several trends: 1) the study of the primary mechanisms of the action of radiation on heredity and study of problems of protecting heredity against the injurious effect of radiation; 2) study of the rules and regulations of occurrence of mutations under the influence of ionizing radiation, ultraviolet rays and visible light; 3) problems of radiation genetics of mammals and man; 4) problems of genetics and cytology of cancer and leukoses caused by irradiation; 5) problems of radiation selection of microorganisms, plants and animals; 6) problems of space genetics.

The main agency for studying the primary mechanisms of the action of radiation on heredity is an analysis of the interaction of radiation energy with molecules of matter. On the cell level this interaction occurs chiefly in the nuclear supramolecular structures in the form of nucleoproteins of the chromosomes, consisting of DNA, proteins and cytoplasmic matter (different organic compounds, water and others). General processes of metabolism, on the background of which the effect of ionizing radiation on the chromosomes of the cell nucleus is realized, are involved in this interaction. The effect of radiation on virus particles is associated with the absorption of the energy of ionizing radiation by nucleic acids and proteins. On the molecular level, primarily, a study is made of the effect of radiation on DNA, isolated from the cell chromosomes or virus particles.

In first place in the analysis of the primary mechanisms of action of radiation on heredity is the problem of the direct and indirect effects of radiation on DNA, the molecules of which constitute the basis of the genetic material in the chromosomes and in the bodies of the majority of viruses. Ionizing radiation, penetrating into the cell, can directly ionize molecules of nucleic acids (the direct effect of radiation) or, by producing radiolysis of water in the cell, can lead to the appearance of free radicals (see Ionizing Radiation), which, on reaching the chromosomes, involve the nucleic acids contained in them (indirect effect). With the direct action of ionizing radiation on the chromosome there are two possibilities: 1. the energy quantum is absorbed locally within the DNA molecule. Ionization of the molecule leads to the occurrence of radiation-chemical processes in the chromosome (a break in polynucleotide chains, the interaction of DNA radicals with oxygen and others), which eventuate in the occurrence of genic mutations, which are permanent chemical changes at various

loci of the chromosome, or in the occurrence of chromosome breaks leading to the appearance of fragments. The latter, combining in new interrelationships, give rise to chromosomal rearrangements. 2. The radiation energy quantum, initially absorbed locally within the DNA molecule, does not injure the locus but migrates, reaches a "weak" point and causes a local injury there in the form of a genic mutation or chromosome break.

With the indirect action of ionizing radiation the energy quantum is absorbed in the cell by molecules of the medium surrounding the chromosome, and, primarily, by water molecules. Radiolysis of water leads to the appearance of free radicals (OH, H, HO_2) which, after reaching the chromosomes, cause chemical changes in them. In experiments with living cells as well as with solutions of DNA it has been shown that the DNA molecules are injured both by the direct and indirect effects of radiation. As far as the genetic material in the chromosomes is concerned, it is injured chiefly by the direct effect of radiation. It has been shown that the number of genic mutations and chromosomal rearrangements after irradiation with the same dose increases with increase in the linear ionization density.

The radiogenetic effect is modified differently by changing the conditions before irradiation, during it, and after irradiation in various cases. Such factors as the effect of oxygen, the combined action of ionizing radiation with ultraviolet and infrared rays, the introduction of various chemical compounds into the cell, the physiological state of the cell, the stage of the cell cycle, etc., are most important.

With increase in the linear ionization density there is a reduction in the relationship between the genetic effect and the modifying factors.

Underlying the chemical protection of heredity against the action of radiation are the following main protective mechanisms: a) the migration of energy from the injured chromosome molecules to molecules of protective agents introduced into the cell, which form complexes with the substances in the chromosome (this is the basic mechanism of protection against the direct action of radiation); b) the removal of oxygen from the cell (hypoxia), which protects against both the direct and indirect effects of radiation; c) the capture of free radicals, formed during water radiolysis by the molecules of protective agents (this is the basic mechanism of protection against the indirect effect of radiation). Chemical protection against radiation with a high linear ionization density has been little studied. For

an analysis of the primary mechanisms of the action of radiation and problems of protection agents with a universal action are of interest. Thus, for example, streptomycin, by forming complexones with DNA, protects the hereditary structures against the action of gamma-rays, alpha particles, and ultraviolet light. At the same time, possessing the power of protecting against combined effects, streptomycin is an antimutagen, which protects the body against the occurrence of a natural mutational process. The latter is of essential importance. The natural mutational process is complex and complicated. It occurs under the influence of a natural radiation background as a result of metabolic disorders, temperature changes, and others. Therefore, protection against it is more complicated than protection against individual mutagenic factors. In man, the natural mutational process is the prime cause of occurrence of a large number of hereditary diseases. Streptomycin constitutes an example of a new class of substances possessing antimutagenic properties. The problem of therapy and prophylaxis of injuries to such a complicated phenomenon as heredity, where "treatment" is accomplished on the molecular level, is given a rational basis and broad prospects because of these discoveries. Working out the problem of antimutagens assumes primary importance for the protection of human heredity.

The genetic effect of ultraviolet rays is primarily associated with the absorption of waves at a wavelength of 2650 A by deoxyribonucleic acid in the chromosomes. The effect of these rays on heredity possesses a number of specific characteristics by comparison with the action of ionizing radiation. Of great interest is the photoreactivation phenomenon, which consists of the fact that visible light (wavelength of 4360 A and others), acting on the cell after irradiation with ultraviolet light, protects the chromosomes against injury. The effect of visible light on heredity is associated with the occurrence of a photodynamic process in the cell, which constitutes the phenomenon of photo-oxidation.

Quantitative analysis of the frequency of point mutations and chromosomal rearrangements has shown that various types of mutations are differently related to the dose of ionizing radiation. For point mutations an exponential relationship to the radiation dose has been established. This speaks for a straight-line relationship between the number of mutations and the dose. Chromosome breaks also occur in a straight-line relationship to the dose. However, the number of chromosomal rearrangements, each of

which requires the presence of two independent chromosome breaks in the nucleus, increases in proportion to the square of the dose. The distance between the breaks entering into the interchange does not exceed one micron. The effect of the intensity of the dose for chromosomal rearrangements is dependent on two separate breaks. In the case of a single irradiation there are maximally favorable conditions for the recombination of chromosomal fragments occurring simultaneously. In the case of fractionated irradiation or in the case of chronic irradiation with a low dose rate, occurring at different times, there are greater probabilities for recombination in the previous order. Extrapolation of experimental data on the straight-line relationship to the dose is evidence of the absence of a threshhold dose for point mutations. Therefore, after prolonged irradiation with any low doses there must be a cumulative effect. There are indications that after prolonged irradiation with a low dose rate repair of a certain number of radiation point mutations occurs; however, the possibility has not been excluded that in this case also part of the point mutations is associated with chromosomal rearrangements.

Previously, the main objects of experiments on radiation genetics were mice. General problems of radiation genetics were studied on the most varied forms of viruses, bacteria, protozoans, plants and animals. For the purpose of modelling the radiogenetic effects suspected in man studies of monkeys (Macaca mulatta) were of great importance. They were begun in the Laboratory of Radiation Genetics of the Institute of Biophysics of the Academy of Sciences USSR, and then were conducted in the Laboratory of Radiation Genetics of the Institute of Experimental Pathology and Therapy of the Academy of Medical Sciences USSR. In the state of Oregon in the United States in 1961 a broad-profile i n s t i t u t e was created for the study of heredity in monkeys, including the study of problems of radiation genetics. Studies of Soviet scientists have made it necessary to revise the quantitative estimate of the effect of ionizing radiation on human heredity. Previously, these calculations were based on the data of genetic radiosensitivity of mice. However, in monkeys genetic radiosensitivity has proved to be two times greater than in mice. For the purpose of a quantitative estimation of the effect of radiation on human heredity it is essential to know the consequences of natural mutation and compare the additional effect caused by the influence of ionizing radiation with them. Material collected in Denmark, United States and England attest to the fact that about four percent of children

born are affected by hereditary diseases as the result of the manifestation of mutations arising under the influence of the natural background of ionizing radiation, chemical and other mutagenic factors. For man the dose of ionizing radiation accumulated in the gonads over a generation (30 years) amounts to about 3 rads. Comparing the rate of natural mutations in man with the number of mutations occurring in monkeys after a dose of ionizing radiation of 1r, it was shown that the magnitude of the dose which doubles the rate of natural mutations in man amounts to about 10r. In 1958, at the suggestion of the Soviet delegation, this figure was accepted as the possible one by the Scientific Committee of Atomic Radiation of the United Nations. Experiments with the effect of radiation on chromosomes in human cells under conditions of tissue cultures (q.v.) also attest to the fact that the dose of about 10r doubles the natural mutation rate in man.

Of the fission products appearing as the result of nuclear explosions, of the greatest importance to man are cesium-137 (Cs^{137}), strontium-90 (Sr^{90}) and carbon-14 (C^{14}). The first two isotopes, formed in the fission process, have half-lives of 30 years. Injuries to human embryonic cells are caused primarily by the action of Cs^{137}, which is uniformly distributed throughout the body and emits gamma-rays. Sr^{90} is deposited in the bones, emits beta-particles, the pathways of which are measured in milimeters in the bones. The entrance of Sr^{90} into the body may be the cause of development of osteosarcomas and leukoses of radiation origin.

For an analysis of the effect of an increased radiation background on human heredity a study of hereditary changes, which, occurring under the influence of radiation, are not manifested immediately in the children of the first generation, will be of special importance. Among these changes are the following: a) dominant visible mutations (achondroplasia, retinoblastoma, neurofibromatosis, Klinefelter's syndrome, Down's syndrome (mongolism) and others; b) recessive visible mutations, sex-linked (hemophilia, some forms of muscular dystrophy and others); c) dominant lethal mutations, both autosomal and sex-linked, as well as lethal recessive mutations which are sex-linked. Of special interest for objective and precise recording of the effect of additional artificial radiation on human heredity is a record of the cases of disease caused by disorders in the set and structure of human chromosomes. Among these diseases are Klinefelter's syndrome, the XXX syndrome (triple-X), Turner's syndrome (the Shereshevskiy-Turner-Bonnevie-Ulrich—

syndrome), Down's syndrome, and Sturge-Weber's syndrome. The frequency with which these diseases occur is comparatively high. Thus, Down's syndrome is manifested, on the average, in one newborn out of 650. Klinefelter's and Turner's syndromes together occur with the same frequency. In the case of a doubling in the number of mutations under the influence of radiation (by comparison with their natural rate) the study of approximately 50,000 children who have from birth suffered from the effects of the increased radiation background can give statistically significant data.

Mutations in somatic cells, which occur in embryos or adults after injury to proliferating tissues, constitute a separate category. Among these changes are leukoses and other cases of malignant growth, partial albinism, changes in the color of a part of the iris, and others. In some cases, leukoses and malignant growth are associated with definite chromosomal changes. It has been shown that in people sick with chronic myelogenous leukemia one of the chromosomes in the 21st pair is shortened because of destruction of a portion of the genetic material in the long arm of this chromosome.

The problem of cancer and leukoses of radiation origin is of definite importance, because these diseases are caused by injury to hereditary cell structures. Therefore, they occur after the effect of low doses of radiation, whose effects accumulate completely or to a certain degree after chronic irradiation. The dose of ionizing radiation of 35-50r doubles the rate of occurrence of leukoses when the bulk of the bone marrow is irradiated. In this connection, irradiation of children is particularly dangerous. Thus, a diagnostic study in pregnancy shows a statistically appreciable increase in the number of cases of leukoses in the offspring. The great duration of the latent period in the occurrence of malignant growth after irradiation shows that changes in the hereditary system of the cell leading to malignancy are not directly associated with the occurrence of various mutations. The carcinogenic effect of radiation is the impetus for the genetic evolution of tissues, leading to malignant growth. The sequelae of the atomic bomb explosions in Hiroshima and Nagasaki with respect to the occurrence of radiation leukoses and cancer are beginning to be expressed only now. It has been determined that the number of cases of leukosis and the occurrence of other malignant tumors are appreciably greater among people who have been subjected to irradiation from these explosions. A special analysis of the remote effects in mice exposed to

The effect of radiation from the experimental explosion of an atom bomb also showed the occurrence of leukoses and other malignant tumors in the animals. After the action of neutrons these diseases occurred more often than under the influence of gamma-radiation.

The sterilizing effect of radiation on human and mammalian gonads is associated with a differentiated influence on various types of embryonic cells. In monkeys and mice it has been shown that the most radio-sensitive are the type B spermatogonia; after them come the type A spermatogonia and, finally, the spermatocytes. After irradiations in doses which kill the type B spermatogonia but are not lethal for type A spermatogonia a characteristic picture of temporary sterility occurs. In this case, a certain time after the period of complete sterility caused by death of the highly radiosensitive type B spermatogonia, the capacity of multiplication is regained at about the time of maturation of the surviving type A spermatogonia. Complete sterility from which there is no recovery occurs after doses which kill all the types of spermatogonia. In man irradiation of the testicles with a dose of 250r causes temporary sterility, from which there is recovery after 12 months. After local irradiation of the gonads complete sterility in man is caused by the action of radiation in a dose of 500-600r.

Studies on the radiation genetics of bacteria, viruses, antibiotic producers, medicinal plants and some other organisms are essential for medicine. At the present time, all the strains, which are industrial antibiotic producers in the medical industry of the USSR and the entire world--producers of penicillin, streptomycin, aureomycin and terramycin--have been obtained by means of radiation selection with the utilization of ionizing radiation, ultraviolet light, radiomimetic agents (ethyleneimine, mustard gas and others). By comparison with the natural strains the productivity of a number of modern strains has been increased by thousands of times by radiation selection. The main center for work on radiation selection of antibiotic producers in the USSR is the Laboratory of Selection of the All-Union Institute of Antibiotics. Producers of vitamins and other valuable feed and commercial agents are also improved by methods of radiation selection. Under the influence of radiation there is also a change in the virulence of pathogenic bacteria and viruses. There are quite a few examples of production of commercially valuable radiation mutants in wheat, barley, tomatoes and peanuts.

As the result of local and general, that is, over the entire planet, increase in the radiation background the problem of means of genetic adaptation of animals, plants,

microorganisms and viruses to this new factor assumes importance. This problem is of particularly great current importance for man. Experiments with plants and microorganisms have shown that genetic evolution on an increased radiation background is accomplished on the basis of selection of mutations increasing the radioresistance of the organisms. In spite of the ideas of some foreign scientists, it is evident that the forms and rates of genetic adaptation to the increased radiation background characteristic of wild species in nature are to no degree applicable to man. In man natural selection has been eliminated as an evolutionary category. It has maintained only part of its significance, keeping down the spread of marked hereditary diseases, leading to mortality in childhood, to a reduction in the number of offspring, etc., and which have not yet submitted to treatment, among populations. Therefore, it is impossible to protect human heredity against the effect of radiation by evolution of his biological properties through genetic adaptation.

For the purpose of protecting human heredity new effective chemical agents are needed which, by acting on the body before irradiation, during or after it, might prevent injury to nuclear structures of embryonic and somatic cells in man caused by the effect of radiation.

Studies of space in accordance with an extensive medical-biological program and the flights of Soviet cosmonauts have laid the bases for space biology (q.v.); sending up various objects on spaceships for cytogenetic studies has led to the creation of space genetics. Now it has been established that the spaceflight factors cause dominant and recessive lethals, a change in crossingover, and nondisjunction of chromosomes in drosophila. In experiments with mice the appearance of chromosomal rearrangements has been found. The same phenomena have been found in experiments with plants. An analysis of the influence of such factors as vibration and weightlessness shows that they also cause genetic changes. During brief flights the effect of spaceflight factors, particularly cosmic radiation (q.v.) on heredity has no practical importance. However, the role of this influence and particularly of cosmic radiation will increase sharply under conditions of long flights into space. This applies both to the organisms--the participants of the closed ecological system of the spaceship and the cosmonauts themselves. At the present time, scientists are using linear accelerators, nuclear reactors, and other sources of ionizing radiation with the aim of studying the effects of heavy particles on the heredity of living organisms. See —

also variation, radiation sickness, meiosis, human heredity, polyploidy, radiobiology, radiology, radiation toxicology, and chromosomes.

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N. P. Dubinin

Radiation Hygiene

Radiation hygiene is a branch of hygiene which takes up the study of the effect of radioactive substances in ionizing radiation on man and the group, the substantiation and development of sanitation standards as well as other measures assuring radiation safety of the population, persons working with radioactive agents, and other sources of ionizing radiation. The aim of radiation hygiene is the prevention of disease and other pathological manifestations caused by the action of radioactive substances and ionizing radiation on man. The creation of radiation hygiene as an independent branch of science in the Soviet Union occurred in the 1950's. The first radiation hygiene laboratories in the Soviet Union were created in the biophysics department of the Institute of Labor Hygiene and Occupational Diseases of the Academy of Medical Sciences USSR. Then, outside of this Institute, these laboratories were converted into scientific research centers on the radiation hygiene of labor, radiation community hygiene, protection and dosimetry and means of individual protection. These laboratories exerted a great influence on the development of radiation hygiene in the Soviet Union.

On the basis of numerous studies by workers in these laboratories the basis was laid for sanitation legislation in the field of radiation safety of the Soviet Union. In 1953, the first official "Sanitation Regulations and Standards for Working with Radioactive Isotopes" were published in the Soviet Union. In 1957 and then in 1960 these regulations were supplemented, revised and published as the "Sanitary Regulations for Working With Radioactive Substances and Sources of Ionizing Radiation." In addition, a number of methods, guides, instructions and sanitary regulations were published on problems of radiation protection and radiation safety. In 1959, the <u>Sbornik Radiokhimicheskikh i Dozimetricheskikh Metodik</u> (Collection of Radiochemical and Dosimetric Methods).

In 1957, in Leningrad, the Institute of Radiation Hygiene of the Ministry of Health RSFSR was created which directed scientific methodological work of radiology groups of the sanitary-epidemiological stations. In all the institutes of hygiene of the Academy of Medical Sciences and in a number of other scientific institutions departments of radiation hygiene were organized. In 1958, the affiliate of the Leningrad Institute of Radiation Hygiene was created. In 1957, at the Central Institute for Advanced Training of

Physicians in Moscow a chair of radiation hygiene was created. In 1960, chairs of radiation hygiene were organized at the Leningrad and Kiev institutes for advanced training of physicians. Radiological groups have been created and are being developed in the majority of oblasts and large city sanitary-epidemiological stations.

The variety of forms of utilization of atomic energy in the national economy, science, and others as well as the variety of means of possible influence of radioactive substances and ionizing radiation on man have been responsible for the development of several branches of radiation hygiene, each of which has a number of trends. The following have been most developed: radiation community hygiene, including elements of nutritional hygiene associated with it; radiation hygiene of labor, within which the development of means of individual protection was initiated and became an independent branch. The branch of physics, which takes up problems of protection against penetrating radiation, is a related one, associated with radiation genetics and is being successfully developed.

The main trends of studies in the field of radiation-community hygiene include the following: 1. Study of the rules and regulations of behavior of radioactive agents in the environment (in the atmosphere, soil, water bodies, underground water), the effect of these substances on the sanitary state of the environment and clarification of the role of various factors determining the degree of accumulation, strength of fixation and degree of migration of radioactive agents under natural conditions. 2. Determination of the rules and regulations to which the processes of passage of radioactive substances from the air, soil, and water into biological structures and into the human body are subordinate. 3. Determination of the correlation between levels of contamination of the environment with radioactive agents and their content in various human tissues. The significance of these studies is determined by the need for creating a theoretical basis for the hygienic evaluation of a situation which has occurred, for prognosis and substantiation of prophylactic measures. Incidentally, they have made it possible to introduce essential changes into the method of calculating the permissible concentrations of some radioactive isotopes. 4. The study of the long-term effect of small quantities of radioactive agents, including natural agents, and low doses of ionizing radiation. This study is made up of the determination of the dose of radiation received by the organism and determination of the effect caused by this dose, including the remote consequences. 5. Substantiation and development of measures directed at the prevention of

contamination of the environment with radioactive agents. 6. The development of methods of sanitary control of sources of contamination and the radiological purity of the atmospheric air, water bodies, underground water, soil, as well as drinking water and food products. 7. Participation in the development of methods of deactivation of drinking water and food products. 8. A search for means and the development of methods which make it possible to reduce the migration of radioactive agents along food chains and to limit the degree to which they accumulate in the human body. 9. Study of working conditions with radioactive substances and sources of ionizing radiation in therapeutic-prophylactic institutions and the development of measures assuring radiation safety of the personnel, patients and population.

On the basis of material obtained, the division of sanita[illegible] legislation which regulate the sanitary conditions in the arrangement of institutions in which work is being done with radioactive substances and emanations, is being further developed; a study is being made of conditions for the removal and deactivation of radioactive waste, the size of sanitary-protective areas around institutions and units which are sources of contamination of the atmospheric air or sources of penetrating radiation, and the existing permissible concentrations of radioactive agents are being made more exact and new ones are being developed for atmospheric air and water as well as for the content of radioactive agents in the human body; the same is being done for the permissible doses of ionizing radiation for the population.

Among the main trends of work in the field of radiation labor hygiene are the following: 1. Study of working conditions during work with radioactive substances and other sources of ionizing radiation with consideration of the entire combination of factors acting (weather, noise, illumination, and others). 2. Study of the properties of radioactive aerosols, their behavior (as well as the behavior of radioactive gases) in work premises and means of their possible influence on man (inhalation, penetration through the skin, on the visual organs, and others). 3. A study of work physiology, general and occupational disease during work with radioactive agents and various types of ionizing radiation. 4. Studies in the field of individual and general dosimetry of various types of ionizing radiation along the line of providing the most effective methods of sanitary control. 5. Hygienic evaluation of conditions, substantiation and recommendation of prophylactic and health improvement measures assuring safe working conditions along the following lines: a) improvement of methods of their application

for purposes of reducing occupational hazards; b) more effective planning, from a sanitary aspect, for work and auxiliary premises; c) means of air-tight sealing of sources of radioactive gases and aerosols as well as ventilation of work premises; d) screening of sources of ionizing radiation. 6. Evaluation of existing methods and the development of new ones in the field of individual and group protection, deactivation of effective surfaces, special work clothing, skin and others. 7. Introduction of corrections and additions to appropriate divisions of existing sanitary legislation in the field of radiation labor hygiene, the development of sanitary regulations for various types of institutions, units, and others, designed for working with radioactive agents and sources of radiation; the development of instructive materials and methods guides, making permissible concentrations of radioactive substances more exact and developing new ones for the air of work premises, and the same for permissible levels of contamination of effective surfaces, special work clothes, skin, and permissible doses for occupational irradiation, etc.

In the field of creation of means of individual protection and protective coverings the main trends are the following: selection, development and study of materials suitable for manufacture of individual protective facilities from them (respirators, insulating suits, special suits, special footwear and others) and protective coverings; the creation of new and perfection of existing means of individual protection designed for work under conditions of an environment contaminated with radioactive agents; complete testing of individual protective agents and protective coverings under laboratory and industrial conditions.

In the field of protection against penetrating radiation and dosimetry under laboratory and natural conditions studies are being made of the following: the properties of the physical parameters of different types of radiation and their sources; protective properties of different materials suitable for manufacture of protective shields; the creation of theoretical bases and methods of calculating protection for the insurance of the safety of those working with various sources and types of radiation; the development of methods of calculating doses received by different organs and tissues of the human body after external and internal irradiation; substantiation of the permissible concentrations of radioactive agents in the air of work premises, in the atmospheric air and in water, substantiation of the permissible doses of different types of radiation, the development of new and improvement of existing dosimetric instruments and methods designed for measuring various types of

radiation in the environment and determining the content of radioactive substances in the human body.

Like any other branch of hygiene, radiation hygiene is a comprehensive science utilizing the methods and results of studies conducted in various fields of science. For the purpose of studying and hygienic evaluation of the sanitary condition of the environment, dosimetric, radiochemical, radiobiological, statistical, and other methods of study used in hygienic practice are utilized. In the study of the effect of radioactive agents and ionizing radiation on man extensive use is made of sanitary-toxicologic, clinical-physiological, radiobiological, physiological, dosimetric, radiochemical, sanitary-statistical and other methods. One of the main factors playing a positive part in the rapid development of radiation hygiene has been the close association of methods of investigation with experimental work conducted both under laboratory conditions and in nature. The extensive utilization of the latest electronic instruments for these purposes, part of which is being designed by physical engineers of hygienic institutions based on specific problems, is making it possible to carry out studies on the current scientific level.

As experience has shown, the most successful and productive form of organization of investigations for solving radiation-hygienic problems is the comprehensive work of hygienists with specialists in different categories (physicists, radiochemists, toxicologists, microbiologists, physiological clinicians, sanitary engineers, geologists and others). The forms of comprehensive work, the number and category of participants may be different and are determined in every specific case in accordance with the nature, volume and complexity of the tasks or problems which need to be solved. In one case, this is assured by the participation of specialists of different categories who are to make up various radiation-hygiene laboratories. In another, the combined participation of a number of laboratories and other divisions of a given institution is necessary. For solving some problems combined participation of other scientific research, planning and designing organizations of the appropriate categories and various enterprises, etc., along with the radiation-hygienic institution, is most productive. Thereby, in all cases the hygienic purposiveness of the studies should be maintained in a clear-cut manner. Such forms of work, by making the accomplishment of the tasks easier and enriching radiation hygiene, make it possible to study the phenomena contributing to or limiting the effect of ionizing radiation on man from all sides, to realize hygienic requirements in practice more rapidly and more completely.

Comprehensive hygienic studies and their realization on the atomic ice-cutter, "Lenin" and in the construction of atomic electric power stations and others can serve as examples.

In working out scientific problems based on requirements or advanced by practice, radiation hygiene utilizes all the results of studies for the needs of practice, with which it is organically associated.

State sanitary control of the fulfillment of the requirements of sanitary legislation on problems of radiation hygiene in the Soviet Union is exercised by the radiology groups of sanitary-epidemiological stations. The forms of sanitary control are in principle the same as those generally accepted in sanitation practice, including preventive and sanitary inspection. In work, contact between radiology groups of the sanitary-epidemiological stations and appropriate scientific research institutions is creating the necessary basis for their productive activity.

Work in the radiation hygiene is being published in the form of monographs, collections as well as journal articles published in the journals Gigiyena i Sanitariya (Hygiene and Sanitation), Meditsinskaya Radiologiya (Medical Radiology), Gigiyena Truda i Professional'nykh Zabolevaniy (Hygiene of Labor and Occupational Diseases) and others. Republic and other conferences are held regularly on various problems: symposia, etc. are held, where various problems of radiation hygiene are discussed. The agency which coordinates scientific research in the field of radiation hygiene is the Subcommittee of Radiation Hygiene of the Scientific Committee of Medical Radiology. See also Doses of Ionizing Radiation, Antiradiation Protection, Radioactive Waste, Radioisotope Laboratory, Radiation Toxicology.

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A. Marey

Radiation Conditions

The radiation conditions refer to the state of a locality after an atomic or thermonuclear explosion on or over it (the boundaries of the suspected areas of contamination, radiation levels, etc.). The explosions of atomic and thermonuclear weaponry are associated with production of a large number of radioactive substances, which include chiefly nuclear fission products (see Atomic Weapons). Their total activity can reach 10^{14} curies, which corresponds to hundreds of millions of tons of radium. In addition, the soil, water, various structures and other objects in the explosion area become radioactive (as the result of neutron irradiation). Thus, for example, the soil acquires an induced radioactivity which reaches 10^{12} curies or more after a ground explosion.

The contamination of a locality along the route of passage of a cloud is called a "radioactive cloud trail." All objects, soil, vegetation, various structures, equipment and people coming into the area of the cloud trail are contaminated radioactively because of the fallout of finely dispersed radioactive particles on them. Contamination of food products and water, the consumption of which can be the cause of internal contamination of man, is of particular danger. Such contamination can be prevented by using means of group protection (see Shelter) or of individual protection (see Gas Mask, Antiradiation Protection). For the purpose of determining the radioactive contamination of food products and water in the area of the cloud trail radiometric studies are used (see Radiometry Under Military-Field Conditions).

The forms and sizes of contamination areas along the trail of the radioactive cloud depend on the type and power of the explosion, the nature of the locality and the soil, the weather conditions (direction and speed of the wind and others). As a rule, the cloud trail is of an elliptical cigar shape with the ratio of the lengths of transverse and longitudinal axes being 1:6-1:10. The dimensions of this ellipse can reach a length of 500 kilometers and a width of 60 kilometers after the explosion of a megaton bomb. Thereby, the intensities of radiation doses along the axis of the trail amount to hundreds of roentgens per hour. In order to avoid injury to people in a contaminated locality and to organize properly the combat activity of troops after the use of nuclear weapons by an enemy, a necessary condition is the prediction of probable boundaries and levels of contamination, which are subsequently made more exact on the basis of data of radiation survey.

For the purpose of predictions the following data are

needed: the type and power of the explosion, the location of the epicenter (center) of the explosion, the average wind speed and direction in the given area. According to these data, the orientation limits of the suspected areas of contamination with different radiation levels are recreated with the aid of special ellipsoidal stencils on a map, that is, the radiation conditions in the locality are determined.

Evaluation of the radiation conditions in the locality as a factor affecting the behavior of troops includes the following: a) determination of the effect of contamination and irradiation on the fighting capacity of the personnel, that is, determination of possible casualties; b) calculation of the radiation doses which the personnel can receive during time spent in the contaminated locality and in going around the locality; c) determination of the most expedient actions and protective measures directed at reducing the injurious effect of radioactive contamination (working out travel routes, selecting the type and determining the rate of movement of transport, the expediency of using various types of shelters, etc.); d) protection of the troops against the possibility of radioactive contamination from an approaching radioactive cloud.

For the purpose of determining the radiation conditions and for more thorough subsequent evaluation of it a radiation survey is made by special military units. Among its tasks are the following: timely detection of radioactive contamination, designation of the boundaries of the contaminated areas with warning signs and finding means of getting around the contaminated areas. Radiation survey can be conducted by means of dosimetric instruments from airplanes (helicopters), tanks, armored carriers or dosimetrists on foot.

For accelerated calculations of doses received by personnel on contaminated territory, for rush determination of the time of the beginning and length of time necessary for getting around the cloud trail, for determination of the permissible duration of stay on contaminated territory by personnel, etc., special tables, graphs, nomograms and dosimetric rulers are used. Underlying all these auxiliary methods are calculated formulas which can be used directly also. For example, the expected dose rate (P_t) at any time, t hours, after the explosion can be determined from the formula: $P_t = P_1 \cdot t^{-1.2}$, where P_1 is the known dose rate at a certain time (for example, an hour after the explosion). The total dose D (in r) received over several hours during the interval between t_1 and t_2 hours after the explosion can be expressed by the following formula:

$$D = \frac{P_1}{0,2} \left(\frac{1}{t_1^{0,2}} - \frac{1}{t_2^{0,2}} \right),$$

Where P_1 is the dose rate in roentgens/hr. one hour after the explosion: t_1, t_2 are the times in hours after the explosion.

The choice of one method or another for obtaining the data depends on the volume of problems posed and the time given over for making a decision. According to the data of the foreign press, for these purposes the utilization of special comput rs, which not only predict the possible radiation conditions but also evaluate different variants of solutions for the organization of combat activity of troops on a contaminated locality, is most promising.

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Yu. Sebrant

Radiation Injuries in Combat

Combat radiation injuries are conditions caused by the injurious factors of atomic (thermonuclear) weapons, namely, penetrating radiation and radioactive agents (see Atomic Weapons).

Under the influence of penetrating radiation (gamma-radiation and neutrons) disease develops which is known by the name of "radiation sickness." (q.v.).

The neutron flux arising during explosions of nuclear weapons is very brief (it lasts fractions of a second)and covers a much smaller area than the area of solid destruction from the effect of the shock wave, within limits of which people die of mechanical injury. However, under some conditions, in sufficiently powerful engineering structures near the epicenter of the blast persons can be left intact who have been subjected to the effect of the neutron flux. Mass injuries with this type of radiation will apparently occur if the so-called neutron bombs are used. It should be kept in mind that in the organism injured by neutrons induced radioactivity occurs. As the result of this, such an organism becomes a source of ionizing radiation and begins to excrete radioactive substances in the urine and stool. In taking care of such injured persons the rules of personal hygiene should be observed with particular care. It should be kept in mind that by means of radiometric examination of the excretions and blood of people with induced radioactivity the dose of neutron radiation which they have received can be determined.

After the effects of high doses of penetrating radiation (more than 500 r) injury can occur to the human skin which has been called "radiation burn" (see Burns). However, after the effect of such doses on a large body surface a serious general condition occurs which can lead to death even before the complete development of the radiation burn. A strictly localized skin injury with large doses of gamma-quanta is not very likely in a combat situation.

Injuries by penetrating radiation in wartime can be either acute or chronic (see Radiation Sickness). Thereby, it should be kept in mind that acute cases occur not only from a single massive irradiation but also after repeated effects of low doses of gamma-quanta. For purposes of preventing injury by ionizing radiation in wartime the permissible doses of penetrating radiation have been established (see Doses of Ionizing Radiation). However, additional irradiation can cause the radiation syndrome. These considerations should be taken into consideration by small and large unit commanders.

For purposes of timely diagnosis and prognosis of penetrating radiation injuries a dosimetric radiation control is set up for service men and some categories of persons working in the civil defense system. With this aim in view, they are supplied with individual dosimeters (see

Dosimetry). People injuried by gamma-radiation are not dangerous to those around them.

Various engineering structures serve as protection against the effect of penetrating radiation: slit trenches, trenches, blindages and special shelters (see Anti-Atomic Protection, Anti-Radiation Protection, Shelter). However, the degree of protection will be different in all these cases.

Injuries by radioactive agents created during the explosion of nuclear weapons occur by two means. First of all, when they are on the surface of the ground, on weapons, on combat equipment and means of transportation, on clothing, footwear, gear or directly on the skin, radioactive agents act on man with gamma-radiation, causing radiation sickness. Coming in contact with the skin or clothing, they, in addition, act on the body with the beta-particles which they emit, causing radiation burns (with doses of beta-radiation of no less than 800-1000 rep). Secondly, radioactive agents can cause radiation injuries by penetrating into man's internal milieu, chiefly, through respiratory organs as well as through the gastrointestinal tract (the incorporation of radioactive agents). Contamination of wound and burn surfaces with radioactive dust is also possible; however, the danger of absorption of radioactive agents is small in these cases. Penetration of radioactive agents into man's internal milieu is associated with the development of radiation sickness, which clinically is similar to the sickness occurring from external irradiation but shows certain differences (see Incorporation of Radioactive Agents).

In order to protect troops and the population in a timely way from injury on territory contaminated with radioactive agents a radiation survey is made of the locality (see Radiation Conditions), and various objects, water and food suspected of contamination and contaminated with radioactive agents are subjected to a dosimetric contamination check (radiometric check).

Protection of the skin against contact with radioactive agents and against the effect of beta-radiation is assured by the utilization of different kinds of shelters and authorized equipment for antichemical protection of the skin (see Clothing). Ordinary clothing only partly protects the skin against the effect of beta-particles. The respiratory organs are protected against radioactive agents with gas masks (q.v.) and by special respirators.

As has been mentioned above, radioactive agents on the clothing and skin represent a danger to the health of the person contaminated by them. In addition, radioactive agents which are present there can contaminate the air and surrounding objects, as the result of which persons contaminated with radioactive agents are dangerous to those around. Therefore, those contaminated with radioactive agents must be subjected to a special medical processing (q.v.). In giving medical aid to those injured by incorporated radioactive agents it should be taken into

consideration that the radioactive agents excreted from the body in the stool and urine can contaminate the patient's environment. Therefore, medical personnel taking care of such patients should observe strictly the rules of personal hygiene.

At the sorting post of any stage of medical evacuation (see Stages of Medical Evacuation) persons with combat radiation injuries are divided into two groups: a) those contaminated above the permissible levels and b) those who are not contaminated or contaminated within the limits of permissible levels. The first group includes persons in whom radioactive agents are found by means of a beta-gamma-radiometer on the clothing, footwear, gear or skin in quantities exceeding the permissible contamination levels. The second group includes those contaminated by penetrating radiation, by incorporated radioactive agents, and persons with contamination by radioactive agents which does not exceed the permissible contamination levels.

Those contaminated with radioactive agents above the permissible levels are subjected to partial medical processing at the stages of medical evacuation which render first aid by a physician (regimental aid station), and to complete medical processing at the stages of medical evacuation which render qualified and specialized medical care (division aid station, separate medical detachment and hospital).

Diagnosis of radiation injuries at the stages of medical evacuation which render first aid by a physician is based on the radiation history (when and where the injured person was in the area of atomic (or thermonuclear) explosion , what protective measures he took, whether he was in a locality contaminated by radioactive agents, whether he was in contact with articles, food or water contaminated by radioactive agents, and others), on the complaints and objective clinical manifestations of the sickness as well as the data of radiometric (qualitative and quantitative) study of the skin, mucus from the mouth, nose and wound surfaces. At the stages of medical evacuation which render qualified medical aid the readings of individual dosimeters are utilized, in addition, for the detection of radiation injuries sustained in combat. The data of individual dosimetric check can be utilized also at the stages of medical evacuation which render first aid by a physician not only under circumstances where there is a low rate of injury (where there are no mass casualties); in specialized therapeutic institutions the data of clinical-diagnostic laboratory tests are also utilized for making the diagnosis of "radiation injury." In these institutions radiometric studies are made by means of apparatus which make it possible to obtain a more accurate idea of the radioactive agents which have caused the given injury.

In filling out the initial medical record cards on persons with radioactive injuries sustained in combat the blue strip is left on the cards. If the injured person is dangerous to those around, the black and yellow strips are also kept on his card (see Forward Area Medical

(Record Card).

The treatment of persons with radiation injuries is conducted, in accordance with the nature and severity of the injury, largely in various specialized institutions. For the mild forms of injury treatment can be given also in convalescent commands.

As the result of simultaneous or successive effects of the injurious factors in nuclear weapons (the shock wave, light, penetrating radiation and radioactive agents) the radiation injuries sustained in combat acquire a combined nature. Complication of radiation injuries with wounds and various injuries caused by ordinary weapons is possible. Injuries by penetrating radiation and radioactive agents can also be combined with the effects of chemical and bacteriological weapons.

In combined injuries various deviations from the typical course of the sickness, caused by the action of each of the injurious factors separately, can occur. As the result of this, in such injuries, a special approach is required to the solution of therapeutic-evacuation and evacuation-transportation problems (see Combined Combat Injuries).

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G. Stepanskiy

Radiobiology

Radiobiology (from the Latin radius--ray; Greek bios--life; and logos--study of) is the science of the effect of ionizing radiation on living organisms (see Ionizing Radiation). The biological effect of other radiations--visible light, ultraviolet and infrared rays as well as radio waves--is studied by other disciplines: by general biology, biophysics, physiology, ophthalmology, hygiene and physiotherapy.

Radiobiology was created as an independent branch of science in accordance with the requirements made on biology by the discovery of x-rays (q.v.) in 1895, by the detection of radioactivity in 1896 (q.v.), by the isolation of radium in 1898 and the utilization of new emanations, unknown in a biological respect, in medical practice and various branches of the national economy shortly after this. During the first 40 years radiobiology developed chiefly in the interests of biological substantiation of the therapeutic use of x-rays (see Radiology, X-Ray Therapy) and the gamma-radiation of radium. For these purposes a study was made of the reactions of tissues and organs under conditions of the pathological process. At the same time, under the influence of observations of the harmful side-effects of radiation, studies were undertaken, directed at investigating the reactions of healthy animals, their organs and tissues. These studies acquired first importance with the discovery of artificial radioactivity in 1934, with the production and utilization of artificial radioactive agents and the development of nuclear energetics. The Use of Atomic Weapons (q.v.) by the United States in the attack on the cities of Hiroshima and Nagasaki (1945), as the result of which a large number of people were exposed to radiation injury, attracted considerable interest to the problems of radiobiology and stimulated the rapid development of this science.

Therefore, radiobiology was developed in the first half of the 20th century in connection with the detection of natural sources of radioactivity and the mastery of artificial sources of ionizing radiation. Under these new conditions ionizing radiations and radioactive isotopes came to be important environmental factors. It was necessary to evaluate the radiation levels acting on the living world and determine the biological significance of natural radiation, to find out the relative biological effectiveness of various kinds of radiation, the sources of which had been obtained by man, to determine the quantitative relationships of the radiation effect (the dose-effect relationship), to clarify the influence of the characteristics of spatial and temporal distribution of radiation on the radiation effect. Along with these tasks the creation of radiobiology was determined by the need for learning the primary radiation-physical and radiation-chemical processes underlying the biological effect of ionizing radiation. At the same time, the study of the initial changes and partly of the

further course of development of reactions to irradiation in physiological systems and in the structures of living organisms was a task of radiobiology. This division also includes clarification of the influence of various environmental factors (temperature, season, oxygen concentration and others) and of the initial state of the irradiated organism, its individual characteristics, characteristics of breeds or varieties, sex, age, et cetera on the biological effect of radiation.

The radiobiological rules and regulations are studied with the use of methods of physics, chemistry, mathematics, utilized for characterizing radiation levels, dose fields, and determination of tissue doses (see Dosimetry, Radiological Units), for the study of the primary processes induced by irradiation as well as with the use of methods of physiology, biochemistry, morphology, and radiation genetics. The study deals with various aspects and stages in the realization of the radiation effect: 1) on the subcellular level (the exchange of the radiation energy in living matter and radiation-chemical manifestations of the radiation effect); 2) on the cellular level (radiosensitivity of nuclear and cytoplasmic structures, morphological and histochemical characterization of the structural elements and interstitial substance), and 3) on the level of the intact organism, its systems, organs and tissues. In accordance with this, there are the following divisions of radiobiology: a) general radiobiology (radiation levels under different conditions of existence, the relative biological effectiveness, the dose-effect relationship with consideration of individual characteristics, initial states and associated influences, the time factor in irradiation, and tissue dosimetry); b) the theoretical basis of the primary biological effect of radiation; c) functional and structural characteristics of radiation reactions in animals.

Radiobiology is the theoretical basis for the utilization of radiation in medicine (see Isotopes, Curie Therapy, Radiology, X-Ray Therapy) as well as for the development of means of preventing and treating radiation injuries to tissues and radiation injuries of intact organisms. Radiobiology underlies certain methods of selection, for example, for purposes of obtaining the most effective antibiotic producers (see Radiation Genetics) and cold sterilization (see the Division of Radiation Microbiology). The development of space medicine, particularly, the solution of the problem of radiation safety for flights into space is assured by working out radiobiological problems. The practical importance of radiobiology is also conditioned by its part in the solution of problems of hygiene (see Radiation Hygiene) posed by the development of nuclear energetics. The problem of the remote effects of an increase in the natural radiation level on the population as the result of the use of radiation in various branches of the national economy and medicine, as well as the problem of radioactive fallout(see Atomic Weapons) have acquired social significance; they are being studied and solved on the basis of knowledge of radiobiology.

The methods of radiobiology play an important part in solving theoretical problems of medical science. Thus, the use of radiation for suppressing the immune specific properties of the animal organism has contributed to an elucidation of the possibilities of tissue transplantation (for example, bone marrow) from one person to another. In radiobiological experiments the characteristics of entrance, distribution and excretion of various substances are elucidated under conditions of radiation-altered permeability or under conditions in the change in the functional conditions of organs caused by it. Suppression of the functions of different organs by means of irradiation has uncovered a new road to finding out the physiological role of various structures. For example, the incorporation of yttrium (Y^{90}) granules by the hypophysis or a strictly localized effect on the hypophysis with very high energy protons (hundreds of thousands of Mev) make it possible to study the effects of exclusion of the gonadotropic influence of the anterior lobe of the hypophysis. Of great theoretical interest are studies directed at finding out the radiosensitivity (threshold of the radiation effect, behaviour of animals in radiation fields which exceed the natural level to a minimum degree, "radiation reception," disorders of analyzer [sense organ in toto] activity and others). Studies of "radiotoxins", on the one hand, and morphological and functional manifestations of the radiation effect, particularly in the central nervous system, on the other, represent two aspects of radiobiology which are of fundamental significance for clarifying the nature of reactions by living organisms and particularly of man to irradiation with different levels of radiation above the natural level. The findings of radiobiology, which make it possible to evaluate the effect of the radiation factor on various organs and tissues under different irradiation conditions, represent the basis for developing pathogenetic therapy of radiation sickness. The principles of treatment of this sickness stem from knowledge of the mechanisms of the disorders which develop under the influence of irradiation in the injuried organism.

Biological activity of ionizing radiation was found during the industrial and clinical mastery of x-rays and radium emanations. These observations stimulated the study of various aspects of the biological effect noted. The first studies were made during the sensations created by episodic reports of the harmful side-effects of x-rays: change in the skin of the hands and general malaise in work with x-rays, epilation observed in a number of cases after the use of x-rays for studying the skull. In 1896, I. R. Tarkhanov performed experiments showing the effect of x-rays on the functional state of the nervous system: after irradiation in frogs a reduction of reflex activity was observed (prolongation of the time of the reflex induced by immersing the frogs foot in a weak solution of sulfuric acid). In 1897, numerous cases of "x-ray dermatitis" were described, and at the International Surgical Congress held in the same year in Moscow, the classification,

pathology and clinical aspects of radiation injuries to the skin were analyzed. In 1902, for the first time a report was given about malignization of a "chronic x-ray ulcer" of the human skin.

The first decade of the 20th century was marked by an expansion of ideas on the radiobiological effects of x-rays and radium emanations. In a number of fundamental studies the effects of new types of radiation were shown on the functional state and structures of various organs and tissues. M. O. Zhukovskiy (1904) studied the effect of radium on the excitability of the motor area of the cerebral cortex in the dog and found an increase in the excitability in the first 10-20 minutes after irradiation with a subsequent reduction of it below the original level. S. V. Gol'dberg (1904), in experiments on mice and experiments with the irradiation of the brains of dogs, observed a number of motor disorders, convulsive phenomena, and paralysis. S. V. Gol'dberg irradiated areas of his own skin, which were then biopsied and subjected to microscopic study. L. M. Gorovits-Vlasova (1906) wrote a monograph in which the radiosensitivity of nervous tissue was emphasized. The works of I. R. Tarkhanov, M. O. Zhukovskiy, S. V. Gol'dberg, L. M. Gorovits-Vlasova, Ye. S. London and others gave us knowledge of the most important aspect of the biological effect of the new types of radiation, which for a long time went without adequate attention. Predominately in connection with these studies Soviet radiobiologists subsequently developed the science of radiosensitivity of the nervous systems of animals and man. Along this line, since the 1920's they studied the conditioned-reflex activity of dogs, in which the brains had been irradiated (M. I. Nemenov, P. S. Kupalov), and later the early manifestations and reactions to minor radiation effects (A. V. Lebedinskiy, G. M. Frank, Yu. G. Grigor'yev, N. N. Livshits and others), spinal cord reflexes (Ye. I. Bakin and others).

The development of knowledge about the effect of radiation on other systems and tissues is associated with studies showing the capacity of x-rays for inhibiting the growth of bones of young animals after acting on the meta-epiphyseal growth cartilage (Perthes). Studies which showed the sterilizing effect of x-rays were of importance. In 1903, H. E. Albers-Shönberg presented data on sterilization by means of irradiation of the sex glands of rabbits and guinea pigs. This trend in research was developed by C. Regaud (q.v.). Changes in the blood and hemopoietic organs under the influence of radiation were studied in detail in 1904-06 by Heineke and others. In 1910-1911 work was done and published on experimental radiation malignization — the production of a skin tumor in a rat under the influence of irradiation (J. Clunet).

Radiobiology studies of the initial period are characterized by a qualitative evaluation of the effects of irradiation on the bodies of animals and man, by the accumulation and systematization of the findings, original generalizations and conclusions. Accurate

quantitative characterization of the effect of radiation was wanting at that time. During the initial period, when data were collected on the biological role of the new emanations and the first conclusions were drawn, there were no methods as yet in existence for measuring the quantity of radiation on the basis of a reproducible unit, which made the comparison of effects, with consideration of dose relationships, difficult. Very slowly, the fundamentals of modern radiation dosimetry were developed. Only in 1908 was the principle of measurement on the basis of gas ionization advanced, which constituted the basis for a series of studies which in 1928 led to the adoption of the roentgen as the international unit, corresponding to the basic requirements of metrology and primarily requirements for reproducibility of the unit of radiation quantity.

Although in the 1930's the ionization method of dosimetry had become quite widely used, only in the 1940's, on the basis of a quantitative analysis was definite progress made in the systematization of knowledge of the radiobiological effects. This was the result of bringing in personnel and facilities for working out the problems of radiobiology which had been advanced by explosions of atom bombs over Hiroshima and Nagasaki, by the growth of the atomic industry, by the extensive use of radiation and radioactive isotopes in the national economy. A more extensive study began to be made of physicochemical, biochemical, morphological, physiological rules and regulations of the effect of radiation. While the previous studies dealt chiefly with the effects caused by local irradiation in tissues, with the development of radiobiology the main interest was drawn to the reactions of living organisms to a whole body irradiation.

As the result of studies made on the basis of careful dosimetry, the quantitative relationships of the injurious effect of ionizing radiation were clarified for different species of animals, and the courses of the curves depicting these relationships were described for various irradiation conditions. It was found that the injurious effect of radiation increases with the dose, describing a curve having a characteristic S shape. For many species of warm-blooded animals and man the minimum lethal dose lies at the level of 200 r after a whole body gamma-irradiation. Thereby, single individuals die which are distinguished by a high individual radiosensitivity. With a dose of 400 r half of the total number of individuals irradiated dies (the LD_{50}). The minimum dose which, as a rule causes death of all irradiated animals is 600 r. However, even after such a destructive effect solitary animals survive, wherein their relative radioresistance is expressed. These radiation doses vary in accordance with the species of animal and the irradiation conditions. In this respect chiefly the nature of the spatial distribution of radiation in the animal's body is of significance; this depends chiefly on the type and energy of the ionizing radiation (see Doses of Ionizing Radiation, Ionizing Radiations).

Under the same conditions of spatial distribution the biological effectiveness of x-rays, beta-radiation and gamma-radiation is almost the same. This is associated with the uniform mode of realization of their effects by means of secondary electrons formed from the interaction with the substance of tissues and fluids by x-rays or gamma-quanta (primary beta-particles in the event of irradiation with beta-rays). Slow neutrons, the biological effects of which are realized through gamma-quanta and protons, possess greater effectiveness. Even more effective in a biological respect are fast neutrons, which exert an action exclusively by recoil protons. High energy protons obtained from particle accelerators and fluxes of alpha-particles have the same or even somewhat greater biological effectiveness. The degree of the latter is connected with the ionization density created by the radiation absorbed. The indices expressing the relative biological effectiveness are of importance for certain conditions of irradiation and methods of evaluation and vary with the dose levels at which the comparision is made, with the dose rate, with the species of animals, and others. Nevertheless, in the interests chiefly of practice, the following indices for the relative biological effectiveness may be adopted: x-rays, gamma-radiation, beta-radiation, one; slow neutrons, three; fast neutrons, protons, fluxes of alpha-particles, ten; multiply charged ions, twenty.

Along with the type and energy of radiation the nature of the time distribution of radiation has an influence on the biological effect. This effect is different in different dose ranges and in different ranges of dose rates; naturally it depends also on the type of radiation, et cetera. In general, fractional irradiation lessens the effect of irradiation (by comparison with a single irradiation). Protracted irradiation with the dose rate of less than 15-10 r per minute exerts less of a biological effect than intense irradiation. Within a certain range (10-15 r per minute to 150 r per minute) the significance of the dose rate is small for many reactions to irradiation. The effect of the dose rate at higher levels and in the area of pulsed (ultrafractionated) irradiation has been less well clarified. In this subject, which is not yet adequately clear, data have been accumulated making it possible to suppose that the biological effect of radiation after intense (up to a certain degree) irradiations is reduced somewhat. The need for clarifying the characteristics of the effects of pulsed irradiation is dictated by the increasing utilization of accelerators which operate under appropriate conditions. Therefore, the S shaped curve expressed the dose relationships of the injurious effect of radiation only in a general form.

After irradiation of animals with doses higher than the minimum lethal dose their lifespans are appreciably shortened.

With subsequent buildup of the doses to 1200-1500 r this time is not much changed, varying within limits of 2.8-3.5 days, whereby for different species of animals these doses are not of absolute

significance. When the level of 20,000-25,000 r is exceeded, with subsequent increase in the dose a progressively greater shortening of the lifespan is again found -- to several hours or minutes ("death under the rays"). Such considerable irradiation apparently leads to "nervous death," whereas after the effects of relatively lower doses death of the animals is preceded by the development of various syndromes (see Radiation Sickness).

Many problems of general radiobiology continue to be inadequately clear. Thus, we need to deepen our ideas of the relative effectiveness of various types of radiation under various irradiation conditions. The characteristics of the biological effect of radiation with different time distributions await further clarification. The significance of many environmental factors, individual characteristics of the organism, its initial functional state and others remain to be clarified and quantitatively evaluated for the effects of irradiation. Systematization and generalization along many lines is needed for the extensive material, at times scattered, which has been accumulated. However, even the quantitative rules and regulations which have been discovered for the effect of radiation constitute the basis for working out problems pertaining to functional and structural changes in the animal organism under the influence of irradiation. Therefore, characteristic of the latest period in the development of radiobiology is the systematizatien of data on the biological effect of radiation and the development of quantitative rules and regulations for this effect under different conditions exerting an influence on the final effect of irradiation.

Ideas on the mechanism of the biological action of ionizing radiation have gone through a complicated route of development. Energy calculations and comparisions with molecular transmutations as well as experimental data obtained on irradiated models have given us a greater understanding of the mechanisms by which the radiation effect is realized in the living organism. Nevertheless, the problem of the primary effect of radiation continues to be actively worked out. For almost sixty years the interpretation of primary processes occurring under the influence of irradiation has been based on ideas about the direct effect of radiation on the biological substrate or ideas of the secondary effects of them on structures of cells and tissues of the body through intermediate chemically active agents. The attention of investigators has been drawn from the very beginning to the discrepancy between the small amount of radiation energy absorbed and the considerable, frequently extraordinary effect of irradiation. The theory of "point heats" (F. Dessauer), which is now only of historical interest, was first based on the principle presented. At the same time, the idea was advanced of chemical transformations leading to the production of very active toxic compounds (R. Werner, Rapp, G. Schwarz). Afterwards, both trends were developed,

on the one hand in the "target" theory (J. H. Crowther, R. Glocker, D. E. Lea) and on the other, in the "activated water" theory (I. Weiss, W. Dale and others). Regardless of the acceptance of the role of the direct or indirect effect of radiation, it was necessary to bring in the after-effect mechanism, which was expressed in a very striking manner at various remote periods after the time of irradiation, for its explanation. From the same standpoint the conception of autocatalytic reactions can be considered in the course of development of processes initially produced by the irradiation effect (Tarusov). Thereby, it is assumed that the after-effect develops as the result of chain reactions, in which catalysis does not come from the intermediate but rather from the end products of the reaction.

The "target" theory based on mathematical analysis of the probability of "hits" in the most vulnerable area, might explain in a satisfactory manner the effects observed in simple systems, for example, after the irradiation of virus enzymes. For explaining the cell changes brought about by radiation effects, the idea of the "target" proved to be inadequate. The "target" theory lost its importance, which was ascribed to it as a system of views capable of giving an integrated idea of the mechanism of the biological effect of radiation. Attempts were made to supplement the basic conception with data on the diffusion of radicals formed under the influence of irradiation and on the basis of their reaction with the molecules of sensitive volumes ("targets").

The primary processes underlying the action of radiation on the biological substrate are at present considered chemical reactions occurring mainly in an aqueous medium. The general sequence of events occurring under the influence of irradiation and then being developed further is represented in the following form. As the result of interaction of radiation with the medium, ionization and excitation of molecules occurs. Their number is small, but it is assumed that the effect which they produce is intensified in the chain of subsequent reactions. Along with the ions formed, which play the chief part, excited molecules may be of essential importance, since the possibility of migration of their energies is assumed. This very brief phase, which amounts to billionths of a second, is replaced by the stage of radiation-chemical reactions accomplished as the result of transformations undergone by the negative and positive ions formed. The result of these transformations is the production of free, unstable and chemically very active radicals -- atomic hydrogen (H) and hydroxyl groups (OH). Another free radical -- hydroperoxide (HO_2) -- which is formed, it is believed, during the course of radiolysis in the body fluids in the presence of oxygen dissolved in them is also endowed with considerable chemical activity. The biological role of hydroperoxide (HO_2), which may be formed during the course of the subsequent transformations, is not entirely clear, since it is more probable that in this case it would break down under the influence of the enzyme, catalase. Subsequently

free, chemically highly active radicals react with dissolved organic substances. These reactions may be of the nature chiefly of oxidation reactions, but also of reducing processes, which are studied chiefly on substrates outside the body -- after irradiation of amino acids, proteins, enzymes and others in vitro. Thus, it has been possible to clarify the comparatively easy oxidizability of sulfhydryl groups (=SH) of the amino acid cysteine under the influence of hydroxyl radicals with the subsequent conversion of cysteine into cystine. The possibility was also established of inactivation of some enzymes containing sulfhydryl groups by means of irradiation, which provided the basis for tying in the development of radiation injury in the living organism with the oxidation of the sulfhydryl groups of enzymes. In the opinion of J. Barron, who advanced this idea, the development of the pathological process is initiated by the inactivation of cell enzymes, which leads to disorders of metabolic processes and subsequently causes functional and anatomic disorders.

The corresponding disorders, which constitute the subject of study of biochemists, physiologists, pathologists and clinicans (see Radiation Sickness) are expressed on the cell, organ, system and organismal levels and are united by certain general rules and regulations of radiosensitivity. According to the principle formulated by J. A. Bergonié and L. Tribondeau, tissue radiosensitivity increases together with the renewal rate of cellular elements and is inversely related to the degree of differentiation of the tissue cell structure. Ignoring the functional reaction to irradiation has led to the fact that on the scale of tissue radiosensitivity, where such rapidly renewable and poorly differentiated elements as lymphoid, sex cells (spermatogonia, oocytes), hemopoietic tissue cells and others were in the first few places, nervous tissue was put in the category of radioresistant tissues. Nevertheless, through the work of Soviet investigators the high degree of reactivity of nerve cells with respect to radiation has been shown. Subsequently, with the perfection of physiological methods of study (electroencephalography, electrocardiography, study of muscle action currents, hemodynamics and others) not only additional proof of the high degree of radiosensitivity of nervous tissue was given but histochemical and morphological equivalents were obtained of this radiosensitivity which was disputed for so long (M. N. Livanov, A. V. Lebedinskiy, G. M. Frank, Yu. G. Grigor'yev, Yu. G. Nefedov, N. A. Krayevskiy and others). This led to the need for a total evaluation of radiosensitivity with consideration of all the aspects of manifestation of the biological effect of radiation.

Aside from the species characteristics, individual properties and initial physiological states, the age of the individual subjected to irradiation also has an influence on radiosensitivity. A particularly high degree of radiosensitivity of growing organisms, distinguished by the exceptional rates of metabolic processes and rapid division of cellular

elements, is particularly great. Embryos, particularly during the period of formation of embryonic layers and organogenesis, are distinguished by exceedingly high radiosensitivity.

Among the influences which can modify radiosensitivity in one direction or another, special attention is attracted by the oxygen tension in fluids and tissues of the body. Reduction in the oxygen concentration reduces the biological effect of radiation; increase, increases the irradiation effect. Study of this, so-called oxygen effect constitutes one of the most important problems of radiobiology. Further study of the "oxygen effect" promises to clarify many unsolved aspects of the biological effect of radiation. Specifically, the "oxygen effect" has brought additional arguments in favor of the predominant role of indirect effects in the realization of the radiation effect in substantiating the mechanisms of the primary action of radiation.

The problem of the possibility of truly stimulating influences of ionizing radiation on living organisms is disputable and requires further study. In this problem, apparently, there are no sufficiently accurate determinations which might assist in the clarification of the controversial concepts. For the purpose of solving this problem the further accumulation of data is needed on the biological significance of low doses of radiation, which exceed the average natural radiation level by only two or three orders of magnitude (see Doses of Ionizing Radiation). The solution of this problem is associated with a determination of the thresholds of the radiation effect for different functional and structural changes and with the study of the activity of analyzers during the observation of animals in fields of ionizing radiation. A most important problem of radiobiology is also the study of the remote consequences of radiation effects on the bodies of animals and man. Thereby, we have in mind the elucidation of the significance of very small but prolonged radiation levels higher than the natural level (see Radiation Genetics).

The further progress of radiobiology is being assured in the USSR by a broad network of scientific research institutions, by the preparation of cadres of radiobiologists at the institutes of the Academy of Sciences USSR, Academy of Medical Sciences USSR, corresponding ministries and offices, the publication of monographs, collections, journals, the holding of congresses, conferences and others. Radiobiology is taught at chairs of biophysics in universities, and in medical colleges in the course of roentgenology and radiology. The future progress of radiobiology implies an expansion of the teaching programs of this discipline, particularly with respect to the divisions pertaining to related problems of physics.

The progress of radiobiology, like that of any other branch of knowledge, is associated with the development and perfection of methods of studying its basic problems. In this connection, the method of

electronic paramagnetic resonance, making it possible to deepen the concepts of the nature and role of active radicals formed in the initial moments of realization of the radiation effect, is attracting considerable interest along with the classic methods. Great significance is being ascribed to studies of transformations of nucleic acids, because these transformations underlie radiation influences on protein synthesis, cell division, and hereditary properties (see Human Heredity, Radiation Genetics).

M. Domshlak, A. Lebdinskiy.

Radiation Microbiology is a division of microbiology given over to problems of the effect of ionizing radiation on microorganisms. Radiation microbiology includes the following group of problems: the mechanism of action of ionizing radiation on microorganisms, morphological and biochemical changes in microbes during irradiation, genetic changes (see Radiation Genetics), radioresistance, protection of microbes against the action of ionizing radiation, the bactericidal effect of radiation, the effect of radiation on antigenic and immunogenic properties of microbes, and radiation sterilization. As a division of general, agricultural and industrial microbiology, radiation microbiology includes a large combination of other problems also.

The Mechanism of Action of Ionizing Radiation on Microorganisms. We can speak of the direct effect of irradiation only in those cases where the water content in irradiated objects amounts to less than three percent. Some living organisms, including bacterial spores, maintain their viability well in the dried state; in this case, death of them from irradiation may be the result of the direct effect of ionizing radiation. At the present time there is an entirely substantiated opinion to the effect that the influence of ionizing radiation on microorganisms takes place largely by the indirect route: as the result of action of active radicals physicochemical disorders occur in the microbe cells containing 75 percent water, as the result of which their early or late death occurs.

After the irradiation of microbe suspensions different degrees of sensitivity of the cells are demonstrated to the action of ionizing radiation. In each microbe population the majority of cells is sensitive to irradiation, whereas some cells prove to be resistant. In order to inactivate these radioresistant cells the application of ionizing radiation in much higher doses is necessary than those at which the main mass of irradiated cells dies. On the basis of a study of the survival curves of bacteria it has been determined that the sensitivity of bacteria is associated with the growth phase of the culture; thus, microbes which are in the lag phase are more resistant to irradiation than cells in other phases of growth. Aside from the size and intensity of the dose, the effect of irradiation depends to a greater degree on the thickness

of the suspension being irradiated. The species characteristics of the radiosensitivity of microorganisms also exert a considerable effect on the effectiveness of irradiation. Spore forms of bacteria are considerably more resistant to irradiation than the vegetative forms. For the purpose of achieving a sterilizing effect during the irradiation of thick suspensions of vegetative forms of bacteria a dose of 500,000-600,000 r is required; for the inactivation of the spore forms of bacteria the dose of radiation is increased to 1,500,000-2,000,000 r (M. N. Meysel', 1955).

The physiological state of microbe cells at the time of irradiation also has an influence on the irradiation effect. It has been shown that starvation of the microorganisms even for a short time considerably increases their sensitivity to the injurious effect of radiation. Microorganisms, more sensitive to heating, prove to be more resistant to irradiation. Gram-positive microbes are more resistant to the action of ionizing radiation than gram-negative microbes. The presence of oxygen in the medium at the time of irradiation enhances the effect of irradiation in connection with its participation in the formation of new free radicals (G. Stapleton, D. Billen, A. Hollaender, 1952).

The temperature factor in the irradiation of microorganisms makes its impression on the effect of ionizing radiation (A. Kelner, N. Bellamy, G. Stapleton, M. Zelle, 1955). Change in the temperature during the period of irradiation and after it has an essential influence on the irradiation effect. With reduction of the temperature a reduction of the effect is observed, which is apparently conditioned by the reduction in the capacity of irradiated cells for carrying out oxidation.

Morphological and Biochemical Changes in Bacteria During Irradiation. Under the influence of irradiation with a dose of the order of one million r microbe cells are destroyed to the point of detritus. Irradiation of microorganisms in doses up to 1,000 r causes an apparent stimulation of cell division processes. As longer observations have shown, cells, with respect to which the stimulation effect is detected, subsequently die. As the result of irradiation in subbactericidal doses there is a marked inhibition of cell division, as the result of which a considerable number of unusual (filamentous, spheroidal) forms of cells are created, which in the final analysis are lysed, leaving hardly noticeable "ghosts" (Z. G. Pershin , S. G. Komm and N. N. Solov'yev, 1957). A small number of cells is maintained and forms a population of cells which later produce microcolonies, part of the cells of which prove to be more resistant to irradiation. When bacteria are irradiated in subbactericidal doses frequently a process of dissociation is observed. Facts are known where microorganisms have lost the ability to form pigment after irradiation as well as the opposite phenomenon, the appearance of various colored colonies or individual colored sectors of colonies in the culture. Bacterial capsules are also subject to changes after irradiation; they are either destroyed from the effect of considerable doses

of gamma-rays or are appreciably reduced in size.

Various functional structures and biochemical systems of microorganisms are very much injured by ionizing radiation. Some biochemical changes in irradiated microorganisms are found even after the effect of radiation in low doses which do not produce visible morphological changes. Other biochemical changes are the results of irradiation in much higher doses. The phosphorus metabolism of microorganisms is most sensitive to irradiation; under the influence of ionizing radiation depolymerization and partial breakdown of the phosphorus compounds in cells occur. After irradiation there is greatest impairment of nucleic acid metabolism (q.v.) and mostly, of deoxyribonucleic acids (q.v.). Denaturation of the protein with the liberation of sulfhydryl groups, observed after irradiation even in low doses, is evidence of considerable changes in the protoplasts of the microorganisms. Subsequently, in the growth process of the irradiated culture denaturative phenomena increase considerably (after-effect).

Directly after irradiation no disorders are noted in the nitrogen metabolism of irradiated microorganisms. Essential growth changes on nutrient media occur for a certain time after irradiation. These changes amount to an increase in the total and nonprotein nitrogen, whereas the percentage of protein nitrogen is reduced. There are data in existence which indicate the greater resistance of respiration and fermentation in microorganisms when they are irradiated. Irradiation in large doses, which injures microbes, does not produce any gross disorders in the enzymatic systems of microorganisms responsible for respiratory processes (M. N. Meysel', 1955).

The Radioresistance of Microorganisms. There are many data in existence which attest to the occurrence of radioresistance in microorganisms, associated with the production of resistant forms as the result of repeated irradiation (E. M. Witkin, 1946, 1947). Thereby, in the radioresistant variants of bacteria there is a reduction in the sensitivity to antibiotics (penicillin and streptomycin). The fact is interesting that radioresistance does not occur in all cells of the microbe population exposed to irradiation but only in individual cells. The process of occurrence of radioresistance occurs gradually as the result of irradiation of microbe suspensions in rising doses. The problem of whether selection of radioresistant forms existing in the population occurs or whether we are dealing with adaptive variation has not been solved (see Variation of Microorganisms). The property of radioresistance is transmitted to subsequent generations of microorganisms.

Protection of Microorganisms Against the Action of Ionizing Radiation. A number of compounds are known which exert a protective effect against ionizing radiation. Protection against radiation, accomplished by means of chemical compounds, is effective only with respect to the indirect effect of radiation. Among the protective

substances are sulfur-containing amino acids (cysteine, methionine, cystine), thioamines (beta-mercaptoethylamine), cyanides as well as alcohols, sodium hydrosulfite and BAL (dimercaptopropanol). These substances, when added to the medium prior to irradiation, exert their effects only during irradiation. The mechanism of the protective effect of these compounds is different.

Cysteine and glutathione belong to protective compounds which possess sulfhydryl groups (Kelner, Bellamy, Stapleton, Zelle, 1955). Cystamine or becaptan (beta-mercaptoethylamine) belongs to the category of strong prophylactic agents possessing a considerable protective effect. A no less strong protective agent is its disulfide form -- cystamine -- the range of which is very broad. As protective agents in irradiation of microorganisms a study was made of certain amino acids and their derivatives -- tryptamine, protamine, serotonin, formate, succinate, pyruvate, serine and others (Stapleton, Billen, Hollaender, 1952). A considerable increase in the protective effects of some amines is noted when they act simultaneously with cysteine. In experiments on microorganisms it has been shown that only those amino acids possess a protective effect against irradiation which are readily oxidized by these microorganisms. Thus, it has been shown that alpha-alanine is utilized in metabolic reactions of a number of bacteria and when first introduced into a nutrient medium exerts a prophylactic effect, whereas beta-alanine, which does not participate in metabolic reactions of the microorganisms, does not protect against the harmful effect of radiation. A protective effect is exerted by saturated monoatomic alcohols (methyl, ethyl, propyl), diatomic alcohols (glycols) and triatomic alcohol (glycerin). Thus, a considerable increase has been noted in the resistance of yeast cells to irradiation after treatment of them with alcohol. The protective effect against irradiation of microorganisms is exerted by other substances also (formic, malic, pyruvic acids, thiourea, sodium acetate and others). Combined protection against irradiation with chemical compounds acting on various biochemical systems of microorganisms is interesting.

Antigenic and Immunogenic Properties of Bacteria in Irradiation. There are very few data on the effect of ionizing radiation on the antigenic and immunogenic properties of bacteria. Study of these problems is interesting from the viewpoint of the possibility of ulitization of ionizing radiation in the production of bacterials. It has been shown by some investigators that O-antigens are more resistant to irradiation than H-antigens (Ye. L. Remennikova, 1956). A reduction in the toxicity of microbes depending on the dose of irradiation has also been established. Agglutinating sera obtained by means of immunization of rabbits with irradiated antigens showed titers no less than the sera, of rabbits immunized with non-irradiated antigen.

Recently, Soviet investigators have obtained data attesting to the possibility of utilization of gamma-rays in the production of

bacterials (V. L. Troitskiy, M. A. Tumanyan, Z. G. Pershina, and others, 1958). From typhoid and dysentery bacteria killed by irradiation (1,500,000-2,000,000 r) the so-called radiovaccine was prepared; "radioantigen" was extracted (an immunogenic polysaccharide-protein complex) and a study was made of its antigenic and immunogenic properties and toxicity. The radioantigens proved to be less toxic than the antigens prepared from formalized microbes. Microbes killed by irradiation did not lose their antigenic properties, and the radiovaccines caused the production of antibodies in the same way as ordinary vaccines (M. A. Tumanyan, A. P. Duplishcheva and T. S. Sedova, 1958).

Radiation Sterilization. In radiation sterilization the death of microorganisms occurs without elevation of temperature ("cold sterilization"). The utilization of ionizing radiation creates the possibility of sterilizing sealed materials. The object of sterilization in the bacteriological industry and in laboratory microbiological practice consists of nutrient media for the cultivation of microorganisms, killed microbial vaccines, "chemical" vaccines -- antigen complexes extracted from the microbes, toxoids, therapeutic sera, glassware, and others. The most important condition for full-scale radiation sterilization is adequate penetrating power of the source. Spore sterilization sources with gamma-radiation possessing considerable penetrating power and a long half-life can be utilized. This group includes radioisotopes of cobalt (Co^{60}) with a half-life of 5.27 years and cesium (Cs^{137}), the half-life of which is equal to 33 years. The final effect of radiation sterilization depends on a number of factors, among which is the moisture content and temperature of the object being irradiated, the species of microorganisms, the degree of seeding, the presence of oxygen and others. Microorganisms which are in the suspensions are more rapidly inactivated by irradiation than those which are in food products and sera. The presence of various organic compounds frequently exerts a protective effect against irradiation. For the purpose of achieving sterility of the object being irradiated, irradiation with a dose of up to 2,000,000 r can be considered adequate for practical purposes, although, according to the data of some authors, microorganisms are encountered which do not lose their viability when irradiated with a dose of 3,000,000-4,000,000 r.

With cold sterilization of products a certain side-effect of irradiation is demonstrated, which is expressed in a considerable change in the color, taste and odor, which are most markedly expressed when the irradiation is carried out with doses of higher than 100,000 r. At the present time, there are several means of eliminating or at least lessening this side-effect of radiation. One of them consists of irradiation in the frozen state. However, such a means of sterilization is complicated by the difficulties of maintaining low temperature during the irradiation process. In view of the fact that changes in the products being sterilized are of an oxidative nature, the most promising method

has been the irradiation of products in the absence of oxygen. In this case, the process of irradiation should take place in a vacuum, in an atmosphere of an inert gas or with replacement of the oxygen by hydrogen.

Cold sterilization is finding progressively more extensive application for the preservation of food products, hermetically packed and designed for prolonged storage. The selection of packing material should correspond to the radiation sterilization conditions also (fine glass, aluminum, plastic, that is, materials which practically do not absorb gamma-rays).

After cold sterilization raw meat acquires an unpleasant odor and taste, which is associated with the production of hydrogen sulfide and methyl mercaptan in the products. Reduction of the irradiation dose leads to a reduction of unpleasant tastes and odors as well as to a shortening of the time the material can be kept. Salted meat products change their color when irradiated, but not to such a degree as does raw meat. On storage of irradiated food products an improvement occurs in their properties; the color is restored, and there is a lessening of unpleasant odors and an improvement in taste. When irradiated food products stood for a month at 37° C a softening of the tissue structure and production of a meat extract were observed (R. S. Khenman, 1957). At a lower temperature better preservation of the product for a longer time and the disappearance of the tastes and odors coming from the radiation effects are noted.

Milk belongs to the category of food products which are very sensitive to irradiation. Unpleasant tastes and odors appear in the milk when irradiated in doses approximately 100 times less than those needed for complete sterilization of it. Therefore, the use of radiation sterilization for the treatment of milk is not very good. Cold sterilization of dairy products is more promising. Vitamins in milk are very sensitive to irradiation. There is most rapid destruction of ascorbic acid and vitamin A; to a lesser degree, carotene and riboflavin. The use of radiation sterilization for fresh eggs had to be stopped because the yolk acquired a pronounced added taste and an unpleasant odor; thereby, the egg white has the appearance of a dense jelly, also with a marked unpleasant odor (R. S. Khenman, 1957).

With radiation sterilization of products of vegetable origin the unpleasant tastes and odors are slight; however, as the result of the fact that the enzymes are not inactivated by irradiation, the preservation of irradiated vegetables is poor. For the purpose of inactivating enzymes the dose of irradiation should be five times greater than that used for achieving complete sterilization. Satisfactory results have been obtained from the irradiation of vegetables in doses of 1,500,000-2,000,000 r. Thereby, there was a considerable prolongation of the time vegetables could be kept; the tastes and odors were hardly noticeable. However, after such irradiation there was a destruction of a considerable part of the ascorbic acid (J. Hickerson, B. E. Proctor,

S. Goldblith, 1956).

The utilization of ionizing radiation is most promising for checking the germination of potato tubers and of grain. For these purposes irradiation with a dose of 10,000-50,000 r is sufficient (J. Kuprianoff, 1955).

Good results are given by irradiation of grain with the aim of destroying insect pests. A radiation dose of 10,000 r is entirely adequate for rapid destruction of insects in various phases of development.

For a final solution to the problem of industrial application of radiation sterilization it is essential accurately to determine the harmlessness of irradiated food products and their suitability as food. Some investigators have expressed concern over the possibility of formation of carcinogenic agents in irradiated food products. However, to date there have been no experimental data confirming this.

The utilization of radiation sterilization in the production of drugs, pharmaceutical and medical preparations is most promising. The use of ionizing radiation in this field is particularly profitable, because among the drugs a large number of costly and rapidly spoiling preparations are known which cannot withstand heat sterilization. The fact is particularly important that the use of ionizing radiation makes it possible to sterilize packed and hermetically sealed materials. The use of radiation sterilization in doses up to 2,000,000 r is possible with respect to a number of pharmaceuticals, antibiotics, hormones, steroids, alkaloids and some vitamins. Good results are given by the use of radiation sterilization for the processing of bandaging material, surgical silk, gauze, cotton and others.

In the production of bacterials sterilization is a necessary process. Usually, nutrient media, glassware, bottles, ampules, laboratory glassware as well as bacteriological production waste are sterilized. In this field the utilization of radiation sterilization can find its most extensive application. The utilization of ionizing radiation for the production of vaccines and the sterilization of nutrient media is most promising. The studies have shown that irradiation of solid agar and liquid nutrient media (Martin's agar, Hottinger's agar, Poppe's bouillon, Martin's bouillon) with a dose of 1,500,000 r does not cause a deterioration in their properties, but comparatively low doses (of the order of 600,000 r) even improve the nutrient qualities of the media (V. L. Troitskiy and others, 1958). The utilization of ionizing radiation for the sterilization of toxoids (diphtheria and tetanus) is possible only with respect to the native preparations. The adsorbed toxoids to a certain degree lose their antigenicity from the effect of sterilizing doses of ionizing radiation. Even less promising is irradiation for purposes of preservation of liquid sera (antitoxic). The utilization of cold sterilization in doses assuring sterility of the preparation causes a partial denaturation of sera

(there is an increase in the viscosity and a change in the electrophoretic mobility; a reduction in the antitoxin titer is noted). However, by the addition of sulfur-containing amino acids to the irradiated sera -- cystein, cysteinamine -- it is possible to protect the sera against destruction during the course of irradiation. By this means it is possible to subject diagnostic agglutinating sera to radiation sterilization.

The use of ionizing radiation is promising for the sterilization of bacteriological production waste (infectious material, contaminated glassware) as well as for clean glassware before it is used in the production process. Ionizing radiation can be utilized along this line if an economical unit is constructed with adequate handling capacity.

Expansion of the area of application of atomic energy for peaceful purposes and reduction of the cost of the sources of irradiation make them considerably more available for general use for purposes of radiation sterilization.

V. Troitskiy, Z. Pershina

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Radioisotopic Diagnosis

Radioisotopic diagnosis is the diagnosis of disease by means of radioactive isotopes. The methods of radioisotopic diagnosis are based on the detection and measurement of radioactive emanations. The methods of radioisotopic diagnosis can be schematically classified in the following way.

1. The methods of radioisotopic diagnosis, based on the principle of isotopic dilution. Among them are a number of methods making it possible to obtain a quantitative characterization of the content of different constituents by the dilution of a radioactive isotope or labelled compound in the body. An example of radioisotopic diagnosis, performed on the basis of data obtained by the method of isotopic dilution, is the determination of the volume of circulating red blood cells in the blood stream. Thereby, the red blood cells taken from the patient are labelled in vitro by isotopes of radioactive phosphorus (P^{32}) or chromium (Cr^{51}), and then are injected into the same patient, and by the dilution of the labelled by the unlabelled erythrocytes in the blood stream the total volume of circulating erythrocytes is judged. The degree of dilution can be judged by the relationship of the radioactivity of a certain volume of injected red blood cells and the radioactivity of the same volume of erythrocytes in a blood sample taken from the patient after complete mixing of the injected labelled erythrocytes with unlabelled erythrocytes. It is also possible to find the volume of circulating plasma based on the data of isotopic dilution. For this, the blood plasma proteins are labelled outside the body with a radioactive chromium isotope ($Cr^{51}Cl_3$). By the dilution of the label in the body after the injection of labelled Cr^{51}-proteins into the blood stream it is easy to calculate the total circulating plasma volume. Measurements of this kind are convenient to make with human blood serum albumin labelled with I^{131}.

The isotopic dilution principle underlies other methods of radioisotopic diagnosis. For example, a determination of the quantity of water in the body important for the surgeon can be made by measuring the radioactivity of the water separated from a blood sample taken two hours after the injection of tritiated water (T_2O) into the blood (see Tritium). In two hours the radioactive water manages to become uniformly mixed with the body fluids. The degree of dilution of the label will be proportional to the total volume of the fluid in the body.

By means of radioactive isotopes of sodium, potassium and chlorine it is possible to find the sizes of the sodium, potassium and chlorine "spaces", that is, the volume in which these electrolytes are distributed in the body, by the data of isotopic dilution. The data obtained can be of diagnostic importance.

2. The methods of radioisotopic diagnosis, making it possible to take into consideration the changes in the rates of physiological processes in different diseases. In them an evaluation is made of the time factor in the course of various processes in the body normally and in pathology. Thus, when diisopropylfluorophosphonate labelled with radioactive phosphorus is introduced into the body the newly formed erythrocytes become radioactive. The label leaves them only when the red blood cells are destroyed. Following this process, which is subordinate to an exponential law, with respect to time, it is possible to calculate the half-life of the red blood cells and their average lifespans. By the same method it is possible to determine the average lifespan of other formed blood elements. The fact that various processes occur according to an exponential relationship, which has been established in many studies, opens up broad possibilities of quantitative characterization of these processes normally and in pathology and for using these data for diagnostic purposes. Specifically, methods of tracer studies of the liver function (q.v.) are based on this. In them consideration is given to the rate at which radioactive dye (for example, Rose Bengal labelled with I^{131}) or colloidal radioactive gold is taken out of the blood stream by liver cells. The same principle--measurement of the clearance rate of the blood with respect to a labelled substance foreign to the body is utilized in tracer diagnosis of kidney diseases (see Kidneys, tracer studies of kidney functions). The rate is characterized by the time needed for reduction of the concentration of the labelled substance in the blood to half. This index is found from an analysis of the blood radioactivity curve as a function of the time which has elapsed after administration of the isotope.

By the rates at which radioactive iron (Fe^{59}) is taken out of the blood, its uptake by the bone marrow and reappearance in the blood (in the composition of erythrocytes) a conclusion is drawn concerning the functional state of the bone marrow and, together with an analysis of other indices, a conclusion about the state of hemopoiesis and blood destruction. By the same token, the differential diagnosis of various forms of anemia is considerably facilitated.

Diagnostic tests serving for the evaluation of the state of the hemodynamics (see Cardiovascular System) amount to a direct measurement of the time intervals spent by the isotope in going through the greater or lesser circulation or various parts of the blood stream. In these tests, the measuring apparatus records the time of the injection of the isotope (usually, Na^{24}) and the time it reaches the part of the body of interest. In modern apparatuses, use is made of automatic recording of these indices.

3. The methods of tracer diagnosis, in which consideration is given to changes in distribution of radioactive isotopes brought about by a pathological process. The classic example of the tracer diagnostic methods belonging to this group is the determination of the functional

state of the thyroid gland by means of radioactive iodine (q.v.). The method is based on the fact that the iodine uptake of the thyroid gland (the index of which is the accumulation of I^{131} or I^{132} in it) depends on the functional state of the thyroid gland: it is increased in hyperthyroidism and reduced in hypothyroidism. Up to 20 different tests have been proposed, in which the radioactive iodine assists in detecting abnormalities of uptake and metabolism of iodine in the thyroid gland. The simplest and most reliable is the dynamic determination of the I^{131} absorbed by the thyroid gland in percentages of the quantity administered. Convenient for this purpose is a DSU-60 apparatus constructed at the Institute of Medical Instruments and Equipment of the Ministry of Health USSR (Scientific Research Institute of Medical Instruments and Equipment), shown in Fig. 1.

[Photograph not suitable for reproduction; available in source.]

Fig. 1. Study of the Patient by Means of a DSU-60 Apparatus. Measurement of activity with a scintillation counter.

By means of apparatuses of another type (gamma radiographs, scanners (q.v.)) it is possible to detail the distribution of radioactive iodine (to take a gammagraph, or scan) both in the gland itself and in the tissues around it as well as in various areas of the body, for example, in the region of thyroid carcinoma metastases. The latter is possible if more radioactive iodine is taken up by the metastases than by the surrounding healthy tissue. In Fig. 2, a gammagraph is shown of a patient's hand with thyroid carcinoma. The dense arrangement of lines corresponds to the site of increased uptake of I^{131} and indicates the location of the metastasis.

A number of methods of radioisotopic diagnosis of other types of tumors are based on the detection of deviations from the usual distribution of radioactive isotopes. Thereby, consideration is given to the possibility of increased accumulation of the isotope or labelled compound in the tumor tissue. This can be caused by metabolic

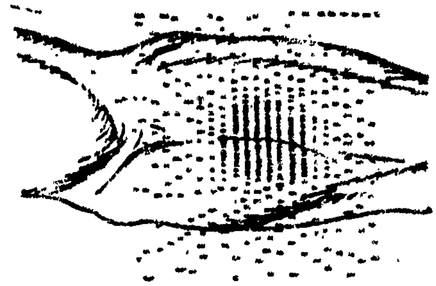

Fig. 2. Gammagraph of the Hand after Administration of Radioactive Iodine. Dense arrangement of lines— thyroid carcinoma metastasis.

characteristics in the tumor cell or by a change in the distribution of the isotope which depends on the level of tumor tissue permeability. Specifically, the radioisotopic diagnosis of brain tumors and tumors of the eye is possible because of an increased permeability of the hemato-encephalic and hemato-ophthalmic barriers for a number of isotopes and labelled compounds (diiodofluorescein, iodinated albumin, Cu^{64}, As^{74}, and P^{32}). In Fig. 3, a study of an eye tumor is shown by means of radioactive phosphorus. A disorder of distribution of radioactive isotopes makes it possible to diagnose congenital cardiac defects. In the presence of a defect in the septum between the right and left heart the radioactive gas krypton (Kr^{85}) administered by inhalation penetrates into the chambers of the right heart and into the blood of the pulmonary arteries earlier and in larger quantities than in a healthy person. Thereby, it is possible to determine not only the existence of the defect but also to make its location and size more definite.

The absence of uptake of diodrast labelled with radioactive iodine and injected into the blood by the kidney indicates functional insufficiency of it. In addition, uptake of the diodrast by the kidney without subsequent penetration of it into the urine indicates the presence of an obstacle to the passage of urine. Such data are very valuable for the diagnosis of kidney diseases.

4. The methods of tracer diagnosis according to data characterizing the absorption and excretion of radioactive isotopes and labelled compounds. Among them studies of th absorption of labelled vitamin B_{12} from the gastrointestinal tract are of essential importance. In the study of the functional condition of the gastrointestinal tract use is made of indices of absorption of fat and protein labelled with

radioactive iodine.

Some of the methods of tracer diagnosis provide information pertaining to the distribution of isotopes and to the rates of processes being studied and to information of different kinds all in the same technique.

In the clinical utilization of tracer diagnosis consideration should be given to the possibility of the radiation hazard for the patient from the oral administration of radioactive substance. Perfection of the measuring technique makes possible the performance of studies with small quantities of radioactive substances, which reduces the radiation hazard to an acceptable level. See also Radioactive Isotopes.

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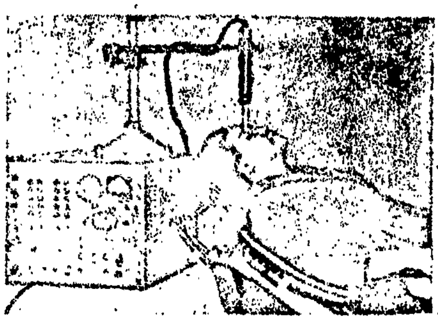

Fig. 3. Diagnosis of Eye Tumor by Increase Absorption of Radioactive Phosphorus. Measurement of the Activity with a Scintillation Counter.

D. Grodzenskiy

Radioisotope Laboratory

The radioisotope laboratory is a combination of rooms and equipment for the performance of scientific research, technical, therapeutic and some other work with the utilization of natural and artificial radioactive isotopes. As a rule, the radioisotope laboratory is included in large institutions: scientific research institutes, central plant laboratories (for example, at enterprises of the metallurgical and machine building industries), clinics, oncological dispensaries and others. In the radioisotope laboratory, radiochemical preparative work, radiochemical and isotopic analysis of different elements and compounds are carried out; methods of radiometry (q.v.) and dosimetry (q.v.) are utilized. In the radioisotope laboratory work is done on the preparation of sources of radiation for utilization for the purpose of gamma- and beta-ray materiology, beta- and gamma-ray therapy, medical gammagraphy as well as for use in instrumentation.

An important requirement for the arrangement, planning and the equipping of the radioisotope laboratory is the assurance of radiation safety for service personnel of the laboratory and elimination of the possibility of contamination of the environment. The strictest requirements are made on radioisotope laboratories in which work is done with open radiative sources. In this case, the degree of possible hazard is determined by the physical state of the radioactive substance, the quantity of it, the type and energy of radiation, the half-life, the relative radiotoxicity and the nature of the technical processes used in the laboratory.

In setting up radioisotope laboratories, consideration is given to the degree of toxicity of radioactive isotopes, for work with which these laboratories are designed. In accordance with the degree of toxicity, they are divided into four groups. In group A are radioactive isotopes with particularly high radiotoxicity, for which the permissible concentration in the air of work premises is equal to $1 \cdot 10^{-13}$ curie per liter or less (Sr^{90}, Po^{210}, Ra^{226} and Ra^{228} and others); in group B, elements with a high degree of radiotoxicity, with permissible concentration in the air of the work premises from $1 \cdot 10^{-13}$ to $1 \cdot 10^{-11}$ curie per liter (Na^{22}, Ca^{45}, Co^{60}, $I^{126,\ 131}$, $Cs^{134,\ 137}$, $U^{230-238}$ and others); in group C, elements with moderate radiotoxicity, where the permissible concentration is from $1 \cdot 10^{-11}$ to $1 \cdot 10^{-9}$ curie per liter (Na^{24}, P^{32}, S^{35}, Fe^{59}, Br^{82}, Sb^{124} and others); in group D, elements with the least radiotoxicity, where the permissible concentration is more than $1 \cdot 10^{-9}$ curie per liter (H^{3}, C^{14}, $N^{13,\ 17}$, Ar^{41}, Sb^{129}, Ba^{139} and others).

Depending on the radiotoxicity group and the activity of the agents utilized at the place of work, work with radioactive agents is divided into three classes.

No special sanitary-hygienic requirements are made on the planning or equipping of laboratories in which work is done corresponding to class III. This work can be done at various tables in general premises outfitted in accordance with the requirements for chemical laboratories. Work corresponding to class II is done in specially outfitted premises located in a separate compartment or in a wing of the building. These premises should include a shower room or medical inspection room and a dosimetric monitoring station. Even higher requirements are made of premises for work of class I. The principle of division into three areas depending on the degree of possible radioactive contamination should be made the basis of the planning of premises for this work (Fig. 1). In the first area various compartments, cubicles, communications and others which are the possible main sources of contamination, are located; in the second area, repair-transport premises are located, designed for repair operations, loading and unloading of active materials and work associated with opening technical equipment and deactivation; in the third area, regular premises for service personnel are located-- operators' (Fig. 2), control board and control panel rooms, associated with the control of processes occurring in the first area.

The combination of rooms of the radioisotope laboratory is determined by the technical plan and the volume of operations and may be different in accordance with the purpose of the laboratory. Nevertheless, a number of components is essential for each laboratory. Among them are: a safe for radioactive preparations, a packing room and a room for metering apparatus. The strictest requirements for protection are made on the safe and packing room, and operations carried out in them belong to classes I and II. Often, these rooms are separated from the rest of the laboratory by an intermediate medical inspection room (or medical washroom).

Rigid requirements are made for the ventilation and air conditioning system. Provision is made for regular monitoring of the content of radioactive dust and aerosols in the air. Air, removed from the premises as well as from cubicles and exhaust hoods should be purified by special filters. The total exchange ventilation is arranged in such a way that the air stream be directed from premises with less contamination to premises with greater contamination. Liquid and solid wastes in the radioisotope laboratory are carefully collected and sent out for burial in special burial places. In laboratories with a large volume of work provision is made for a special sewage system with a sewage purification system with respect to radioactive contamination.

Radioisotope laboratories in which work belonging to classes I and II is conducted are furnished with special protective equipment. Work with alpha- and beta-emitting preparations is done in air-tight cubicles and exhaust hoods with the rubber gloves set into them.

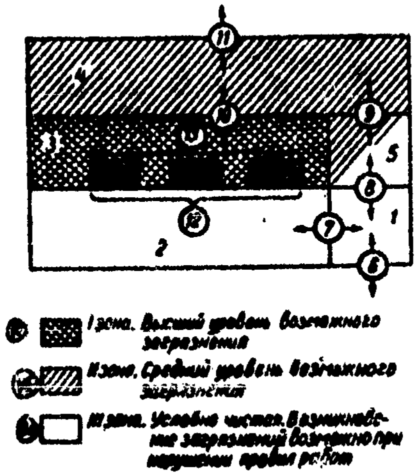

Fig. 1. Simplified diagram of trisonal planning and the relations between various groups of premises: 1. vestibule, toilet, shower rooms, closets for special suits and special footwear; 2. operator's and auxiliary premises; 3. area where equipment is located; 4. repair-transport zone, isotope safe, solid waste, air outlet ventilation compartments servicing areas I and II; 5. medical inspection room or medical washrooms; 6. outside entrance; 7. passage from the vestibule to rooms in the third zone; 8. passage to the medical inspection room or medical washrooms; 9. passage from the medical inspection room or medical washroom to area II; 10. passage from area II to area I; 11. exit from area II to the outside for the purpose of receiving isotopes and removing waste; 12. main places of work in the operator's room; 13. room for work associated with opening equipment; 14. zone I [also called area I in this text]. Highest level of possible contamination; 15. area II. Medium level of possible contamination; 16. area III. Conditionally uncontaminated. The occurrence of contamination is possible when work regulations are violated.

Gamma-emitting preparations are also treated in air-tight cubicles and under exhaust hoods which, however, are furnished with additional lead or cast iron protection. Work with highly active sources of high energy beta-radiation and gamma sources is done by means of remote controlled manipulators. The preparations are transported from the safe to the packing room and then to the places of work by means of conveyers passing under protective cover. In small laboratories, the preparations are transported between places of work in protective containers (Figs 3 and 4).

In medical radioisotope laboratories usually both enclosed and

Fig. 2. Operator's rooms in laboratories for production of luminous compounds: 1. system of air-tight cubicles with oversleeve gloves: 2. protective sliding cast iron shields; 3. glass partition; 4. buttons for elevators for underground storage of products; 5. machinery for moving shields.

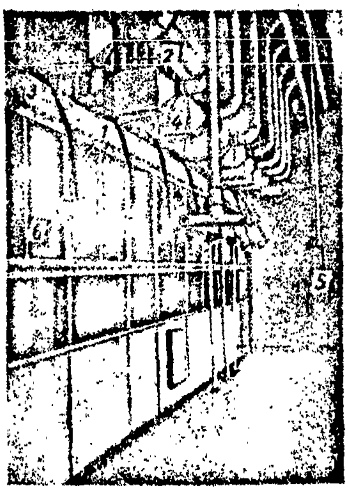

Fig. 3. Repair-transport area of laboratories for production of luminous compounds: 1. system of air-tight cubicles from the repair-transport area side; 2. glass partition; 3. detachable windows for repair of equipment; 4. filters of cubicle ventilation system; 5. air ducts for supplying air to the air suits; 6. lights for illuminating inside of cubicles.

open sources of radiation are used. Such laboratories are included in the oncological dispensaries, large therapeutic institutions and scientific research institutes.

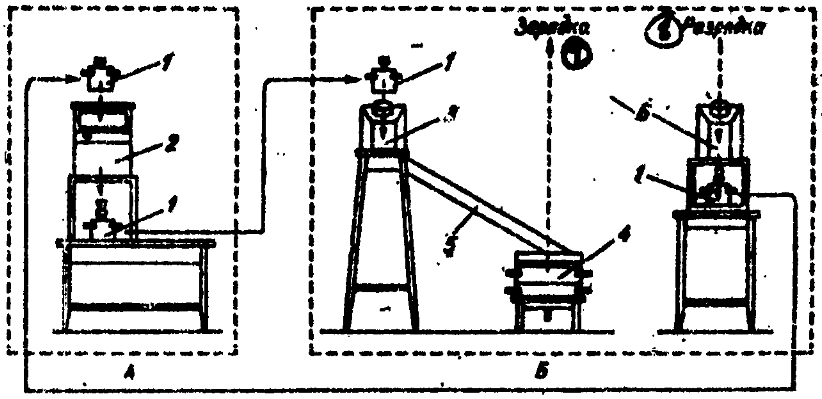

Fig. 4. Diagram of the working process; A. safe room; B. manipulations room; 1. revolving type container; 2. protective work table of safeguard; 3. manipulations table; 4. sterilizer ; 5. conveyer; 6. protective table for treatment of the capsules after discharging them and for placing them in containers (the thick solid line with arrows shows the transportation of containers with the capsules); 7. charging; 8. discharging. (A. Ya. Berlovskiy).

In medical radioisotope laboratories work is done corresponding to classes II and III. Thereby, work of class II is done in the safe-rooms and packing rooms. With the utilization of radioactive isotopes for therapeutic purposes, a number of operations of class II are conducted in the procedures and operations rooms. The bulk of the work with the utilization of isotopes for diagnostic purposes belongs to class III.

The entrance to the safe-rooms, packing room and some procedure rooms is guarded by a dosimetric station or medical inspection room. The equipment and finish of these rooms, ventilation, heating and the sewage system are in accordance with the requirements of sanitary regulations for work with radioactive agents of class II. The other rooms of the radioisotope laboratory (the bulk of the procedures and operations rooms, premises for metering operations, observation rooms, etc.) are equipped in accordance with requirements for operations of class III. All the premises of the medical radioisotope laboratory are usually located in a separate compartment or in a special building.

With the use of enclosed sources of radiation alone the sanitary-hygienic requirements are somewhat different. Since in this case the possibility of contamination of the environment with radioactive agents can occur only through a break in the hermetic sealing of the preparations, the main attention is given to problems of protecting the

service personnel against external irradiation and to checking on the hermetic sealing of the envelopes containing the preparations. Protection against external irradiation is assured by the use of protective equipment and remote controlled units (see Antiradiation Protection (Physical)). Apparatuses used for gamma-ray therapy can serve as an example. Sources of radiation in these apparatuses are enclosed in protective containers, and they are operated by remote control. The irradiations are conducted in premises with protective walls. Observation of the irradiation is made by means of television apparatuses or through observation ports with protective glass. When gamma-ray preparations are introduced into the body cavities, tissues, or when they are placed on the body surface, use is made of sliding protective shields.

See also Radiation Hygiene.

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V. Khrushchev

Radiological Units

Radiological units (and magnitudes) are units of measurement of the magnitudes utilized in radiology.

In the USSR, the units of x-radiation, gamma-radiation and radioactivity are defined by GOST /All-Union State Standard/ 8848-58, enacted 1 January 1959. The GOST partly takes into consideration the recommendations of the International Commission on Radiological Units and Measurements (ICRU).

The International Commission on Radiological Units and Measurements was organized at the First International Radiological Congress (1925). The Commission works on the basis of material of corresponding national committees, is controlled by radiological congresses, and is connected with the World Health Organization (WHO). The recommendations of the International Commission on Radiological Units and Measurements are revised systematically in accordance with the expansion of the field of application of radiation.

Below, definitions of radiological units according to the GOST are presented, as well as the definitions of some radiological units of interest which have been included in the recommendations of the International Commission on Radiological Units and Measurements, and, finally, definitions of radiological units encountered in publications which have not been included either in the GOST or in the recommendations of the ICRU-- either they are outdated but are still used or have gone out of use completely but require comparative evaluation for reading the literature of previous years. With respect to the latter, it has been pointed out that these are outdated units. In the group units are included based on the ionization method of measurement, photometry, colorimetry and others. In addition, the so-called biological units, based on standard reactions which served for reproduction of irradiation conditions in the initial period of development of dosimetry, are given.

As the unit for the dose of x-radiation and gamma-radiation the roentgen has been adopted (r). In accordance with the GOST, the dose of x-radiation or gamma-radiation in air from which the conjugate corpuscular emission per cubic centimeter of air (possessing a mass of 0.001293 gram at 0° C and 760 millimeters of mercury) produces ions in it carrying a charge equal to one electrostatic unit of each sign (in the centimeter-gram-second system) is taken as one roentgen.

The dose of x-radiation or gamma-radiation is a measure of the radiation based on its ionizing power. This definition coincides with the definition given by the ICRU: "the irradiation dose" (or the "exposure dose").

In accordance with the GOST, the dose characterizing the fields of x-ray and gamma-radiation should be measured in roentgens. The use

of the roentgen as the dose unit is accepted for the measurement of radiation with quantum energies up to 3 Mev.

In practice, derived values of the roentgen are utilized: the megaroentgen (10^6r), kiloroentgen (10^3r), milliroentgen (10^{-3}r), microroentgen (10^{-6}r), which can be designated, respectively, Mr, kr, mr, μr.

In calculating the dose created by beta-radiation of radioactive isotopes in tissues, the following formula is used:

$$D_\beta = 88 \cdot c \cdot T_{1/2} \cdot E_\beta,$$

where: D_β is the dose (in roentgens) liberated from complete disintegration; c-- the concentration of the isotope in millicuries per kilogram of tissue; $T_{1/2}$ is the half-life in days; E_β, is the mean particle energy in Mev.

The roentgen per second (r/s) has been accepted as the unit of intensity of the dose of radiation. The quantity of energy which passes through a small sphere surrounding a point with a uniform cross-sectional area per unit time is called the intensity of radiation (the density of the radiation energy flux) at the given point. The erg per square centimeter or the watt per square centimeter (abbreviated: erg/cm^2 and w/cm^2) serves as the unit of radiation intensity.

The magnitude of the neutron flux is characterized by the number of neutrons passing through a perpendicular beam with an area of one square centimeter per second.

The unit of the absorbed dose of x-radiation or gamma-radiation is the rad (abbreviated rad). According to the GOST a dose of x-radiation or gamma-radiation equal to 100 ergs per gram of irradiated substance by the irradiated substance is taken as 1 rad.

In practice, derived values of the rad are used: the megarad (10^6 rad), kilorad (10^3 rad), millirad (10^{-3} rad), microrad (10^{-6} rad), which can be called respectively M rad, k rad, m rad, and μ rad.

From what has been stated above, it is seen that in radiology the concepts of the absorbed dose and the irradiation dose are accepted. In many cases the absorbed dose can readily be calculated on the basis of measuring the value of the irradiation dose. In connection with this, the roentgen, as the practical dose unit of irradiation (exposure dose) for x- and gamma-rays remains the basis of practical dosimetry. The absorbed dose is determined by means of measuring the irradiation doses in roentgens (characterizing the radiation field) with consideration of the composition of the medium being irradiated. In practice, under conditions of electronic equilibrium the absorbed dose is determined by calculation according to the following relationship: the absorbed dose D is proportional to the irradiation dose, R(D=fR). For the case of x- and gamma-radiation and where the

absorbing medium is air, the value of f is 0.877 rad per roentgen for any quality of these radiations; for other media, f changes with the atomic composition of the substance being irradiated and the quality of the radiation.

The integral absorbed dose in a given area is the name of the energy transmitted to the substance by ionizing particles in this area. According to the recommendations of the ICRU the unit of the integral absorbed dose is the gram-rad (g-rad); 1 gram-rad is equal to 100 ergs (ICRU).

The intensity of the absorbed dose is the term for dose absorbed per unit time. The unit of intensity of the absorbed dose is the rad per unit time (ICRU).

The roentgen equivalent physical (abbreviated rep) has two definitions. First, the dose of any ionizing radiation which leads to absorption of energy of 88 ergs by the irradiated tissue, that is, the energy which is absorbed by tissue per gram of air when the radiation dose is equal to 1 r, is taken as 1 rep. Later, the dose of any ionizing radiation which leads to absorption of 95 ergs of energy per cc (1 gram) of wet tissue from irradiation with hard x- or gamma-rays began to be taken as 1 rep.

The dose unit for fast neutrons is designated by the symbol "n" (Abershold and others, 1941). A dose of fast neutrons equal to 1 n produces ionization in a Victoreen dosimeter, calculated for 100 r, equivalent to the ionization produced by a dose of x-rays equal to one roentgen. 1 n is about equal to 2.5 rep is about equal to 190 ergs per gram of tissue. 1 n/sec is about equal to $5.8 \cdot 10^8$ fast neutrons per square centimeter per second.

In American works sometimes the dose of fast neutrons is designated by the symbol N. This designation applies to measurements made by means of the Victoreen dosimeter calculated for 25 r.

With the introduction of the rad other units in the field of neutron measurements as well as the rep went out of use.

The linear energy loss is characterized by the energy transmitted by an ionizing particle to the surrounding medium per unit section of its pathway and is expressed in kiloelectron volts per micron.

In the literature the following magnitude is encountered: "specific ionization," determinable by the linear density of ions along the pathway of an ionizing particle (the number of ion pairs per micron of substance).

The unit of activity of a radioactive isotope is the curie (c)-- the activity of a preparation of a given isotope in which $3.7 \cdot 10^{10}$ disintegration events occur per second. According to the ICRU definition (1956), the curie is the unit of the quantity of radioactive substance estimated according to its radioactivity. The quantity of a radioactive nuclide in which the number of disintegrations per second is equal to $3.7 \cdot 10^{10}$ is taken as 1 curie. In practice, derived values of the

curie are used: the megacurie (10^6 curies), kilocurie (10^3 curies), hectocurie (10^2 curies), decacurie (10 curies), millicurie (10^{-3} curie), microcurie (10^{-6} curie), respectively, Mc, kc, hc, dc, mc, and μc.

In some countries, the rutherford (rd) has been accepted as the unit of activity; it is the activity of the quantity of radioactive preparation in which 10^6 disintegrations occur per second. The derivatives of this unit are the following: millirutherford (mrd, 10^{-3}rd) and microrutherford (μrd, 10^{-6}rd). At the present time, the rutherford is an outdated unit.

For the purpose of measuring specific activity the following units are utilized: the curie per liter (curie/l), millicurie per liter, microcurie per liter, curie per kilogram, millicurie per kilogram, microcurie per gram.

Concentration of radioactive agents in a fluid or gas is customarily measured in emans ($\mathcal{E}$). One eman amounts to 10^{-10} curie per liter of fluid or gas (10^{-10} curie per liter). The Mache unit amounts to 3.64 emans or $3.64 \cdot 10^{-10}$ curies per liter.

The quantity of radioactive strontium (estimated by its radioactivity), referred to a gram of stable calcium, has the name of the strontium unit (sunshine). One sunshine equals 1 micromicrocurie (or picocurie, 10^{-12} curie) of radioactive strontium per gram of stable calcium. This figure is encountered in the literature for the assay of the fallout radioactivity of fission products (after atomic bomb explosions) on the ground (see also Doses of Ionizing Radiation).

According to the GOST the radium milligram equivalent (mg-eqra)--the gamma-equivalent of a radioactive preparation whose gamma-radiation under a given type of filtration and under identical measurement conditions creates the same dose intensity as gamma-radiation of 1 milligram of radium of the radium State standard of the USSR for a platinum filter 0.5 millimeter thick-- is taken as the radium gamma-equivalent unit of a radioactive preparation. It has been accepted that 1 milligram of radium at a distance of 1 centimeter from a 0.5 millimeter thick platinum filter creates 8.4 r per hour. For the purpose of characterizing the sources of gamma-radiation, particularly those used in telegammatherapy, the intensity of the dose created by 1 curie of the preparation per hour at a distance of 1 meter is used. This index is designated by the abbreviation rhm. One curie of radium (0.5 millimeters of platinum filter creates 0.84 rhm; 1 curie of radioactive cobalt (Co^{60}) creates 1.30 rhm; 1 curie of radioactive cesium (Cs^{137}) creates 0.36 rhm; 1 curie of radioactive tantalum (Ta^{182}) creates 0.61 rhm; 1 curie of radioactive gold (Au^{198}) creates 0.22 rhm; 1 curie of radioactive iodine (I^{131}) creates 0.24 rhm. In clinical practice, for the purpose of estimating doses created in a room by gamma-radiation from preparations taken by mouth it is also important to know this index.

The gamma-constant of a radioactive isotope is the following:

the intensity of the radiation dose expressed in roentgens per hour (r/hour), created by gamma-radiation of a point source with an activity of 1 millicurie at a distance of 1 centimeter.

On the basis of a comparison of the gamma-constants it is possible to arrive at an expression of the activity of a radioactive preparation in radium milligram-equivalent units. Thus, for example, 1 millicurie of Co^{60} is equal to 1.6 milligram-equivalents of radium.

For the purpose of comparing the effectiveness of the doses of ionizing radiation absorbed and which have been transmitted to a substance by different methods, the concept of relative biological effectiveness is used (abbreviated RBE). The relative biological effectiveness of x-radiation produced at an energy of 250 kv is taken as the unit of relative biological effectiveness. The biological effectiveness of any type of radiation depends on many factors. Therefore, the relative biological effectiveness cannot be expressed in a general form by a single coefficient and varies in accordance with a multitude of factors, such as the type and degree of the biological reaction (and, therefore, the magnitude of the dose absorbed), the intensity of the dose absorbed, the fractionation of the irradiation, the level of oxygen saturation, the pH and temperature. The relative biological effectiveness of any type of radiation cannot be uniformly related to the nature of the particles (protons, alpha particles or others) without regard for their energies. It is made clear from the ratio of the specific ionization created by the radiation being compared to the specific ionization created by x-radiation produced at an energy of 250 kv (which is considered, on the average, to be 100 ion pairs per micron of water), or is characterized by LEL of 3.5 kev/micron (see Proton Radiation) [LEL, rendered LPE in Russian, means linear energy losses]

It has been accepted that x-radiation and electron and positron fluxes of any energies have the same coefficients of relative biological effectiveness. With consideration of the defects in the determination of the magnitudes of the relative biological effectiveness, inherent in the reb unit also (see below), it is recommended that their use be limited to situations pertaining to protection against radiation.

The Roentgen Equivalent Biological (reb, rem): an RBE-dose unit equal to the product of the dose expressed in rads and the corresponding value of the RBE pertaining to a given manifestation of the radiation effect. According to the recommendation of the ICRU, x-radiation or gamma-radiation (with a dose intensity of about 10 rads per minute), at which the value of the LPE is equal to 3 kev/micron, serves as the standard of comparison.

In the recommendations of the International Commission for Radiological Protection (1955) the following definition is given: the absorbed dose of any radiation which causes the same biological effect

as 1 rad of x-radiation acting on the same area and possessing an average specific ionization of 100 ion pairs per micron of water, referred to an equivalent pathway in air is taken as 1 reb. The dose in reb units is equal to the dose in rads multiplied by the appropriate RBE coefficient.

At the present time, the following units are only of historic interest.

The "e" (Friedrich) dose unit of x-radiation. His conclusion was based on the ionization effect without consideration of atmospheric pressure, temperature or the effect of the walls of the chamber, which excluded accurate reproducibility of this unit. Therefore, the readings expressed in "e" units were unreliable. According to Krönig and Friedrich, the erythema dose was considered to be 170 "e".

The R dose unit of x-radiation used in Germany since 1924 (Küstner, Behnken) applied to air at a temperature of 18° and a pressure of 760 millimeters of mercury and, therefore, is somewhat greater than the international roentgen unit (1 R=1.066r). It has gone out of use since the introduction of the roentgen (1928).

The R dose unit of x-radiation used in France (Solomon) was defined as the ionization created by 1 gram of radium per second at a distance of 2 centimeters from the chamber when a filter of 0.5 millimeter of platinum is used; it depended on the shape of the radium preparation, the effect of the walls of the chamber and others. One Behnken R unit is equal to 2.25 Solomon R units.

The F Fürstenau dose unit of x-radiation was based on the change in the conduction of selenium under the influence of irradiation. Depending on the energy, 1 F is equal to approximately 1-4 r.

The X dose unit of x-radiation (Kienböck, 1913) was based on the degree of blackening of a chlorobromide gelatin emulsion applied to a strip of paper after appropriate treatment of it (after irradiation) and comparison with the standard scale of the Kienböck quantimeter. The measurement in X units was associated with numerous defects (variations of the readings depending on the processing conditions and individual estimation of the degree of blackening and others). One X is approximately equal to $\frac{1}{2}$H or 1/10 ED of soft x-radiation or 25 r of hard radiation.

The S-N (Sabouraud, Noire) dose unit of x-radiation was based on the degree of change in the color of a tablet containing barium platinocyanide (the double salt of barium cyanide and platinum) under the influence of irradiation toward a shade which corresponded to that produced by the erythema dose, that is, to a reaction occurring after 10-15 days in the form of a slight erythema (ED). Along with its other defects (see the comment about the X unit) the S-N unit was unsuitable for estimating doses less than that which caused erythema. One S-N corresponds approximately to 250 r of hard x-radiation.

For the purpose of reproducing identical irradiation conditions

the unit skin dose, HED (Hauterythemdosis or Hauteinheitsdosis) was introduced (Seitz and Wintz, 1920); the HED is the quantity of hard x-radiation, which after a single irradiation of an area of skin 6x8 centimeters with an FSD of 23 centimeters, causes a slight erythema of the skin after a week, a brownish color of it after three weeks, and a definite brown color, after six weeks.

Depending on variations in the radiosensitivity of the skin in different subjects (the effect of individual sensitivity, sex, age, different conditions) and of the skin in its different areas, there may be variations of 10-15 per cent. The subjective estimation of the reaction also has an influence on these variations. According to subsequent measurements (Grebe, Martius, 1924), 1 HED=600r of hard x-radiation.

The H (Holzknecht) dose unit of x-radiation was based on the degree of change in the color of tablets of the Sabouraud and Noire type. By means of the Holzknecht chromoradiometer, it was possible to measure in H units radiation doses which were fractions and multiples of the unit skin dose, HED.

Measurements in H units were very common before the beginning of the 1930's. Thereby, in the practice of x-ray therapy, it was customary to express radiation doses in fractions of the HED by means of the H unit: ½HED (6H); 1/3HED (4H), et cetera.

The relations for the purpose of expressing the dose of hard x-radiation in per cent of the HED by means of the H unit are shown in Table 1.

In the case of hard x-radiation 1H is equal to approximately 50r.

In the early publications, the concepts "erythema dose" (ED) or "normal dose" (ND) were also encountered. By means of these units a definition was given to the quantity of x-radiation of medium hardness emitted by an ion-accelerating tube which after approximately two weeks produced a slight erythema on the skin of the hands. One ED is approximately equal to 400r.

The relationship between the dose and the erythema effect under otherwise equal conditions is associated with the characteristics of the spatial distribution of radiation. Therefore, depending on the voltage at which the x-rays are produced erythema can be caused by irradiation in doses from 200r (very soft radiation) to 1300r (very hard radiation obtained from voltages of 2-3Mev). When x-radiation obtained on betatrons and linear accelerators at 4-30Mev is used in therapeutic practice, the skin reaction cannot serve for estimating the degree of the radiation effect.

As a criterion for defining the dose of x-radiation previously a biological unit was also used which was given the name of the "epilation dose." It was equal to the dose of radiation sufficient to cause loss of hair of the scalp (without an inflammatory reaction) in a

Table 1

1 HED (в %)	H (округленно) 2
100	12*
90	11
80	9.5
70	8.5
60	7
50	6
40	5
30	3.5
20	2.5
10	1

*Depending on a number of conditions (see HED) 100% HED may be expressed by 10-14H. 1. in %; 2. in round figures.

child 10-15 years of age two weeks after the effect of x-rays of medium hardness. The epilation dose was estimated to be 3.5-4.0H or 8X according to the data of colorimetry and photometry.

The dose of x-radiation which caused death of all 20 irradiated mice in four weeks was called the mouse dose. This dose was proposed as a biological unit for characterizing the degree of the radiation effect. The mouse dose was considered 25-30X. It corresponds to the concept of the minimum absolutely lethal dose after an observation period of 30 days ($MALD_{100/30}$).

The dose of x-radiation necessary to check the growth of the rootlets (or shoots) of the horsebean (Vicia faba equina) was called the "bean" dose. The radiation effect of the bean dose was estimated by the lengths of the shoulders of the roots and the degree of growth inhibition of the branch rootlets of six-eight beans moistened for 48 hours and then exposed to irradiation. The full bean dose was equal 60 per cent of the HED.

In radiology, as in other fields of science and engineering, prefixes are used for forming fractional or multiple units (Table 2).

See also Barn, Gamma-rays, Gamma-constant, Dosimetry, Doses of Ionizing Radiation, Curie, Neutron Radiation, Radioactivity, Radiobiology, Rad, Radiometry, Roentgen, Roentgen Rays.

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Table 2

Приставки	Числовое значение	Сокращенное обозначение	
		русское	международное
Пико	10^{-12}	п	p
Нано	10^{-9}	н	n
Микро . . .	10^{-6}	мк	μ
Милли . . .	10^{-3}	м	m
Санти . . .	10^{-2}	с	c
Деци	10^{-1}	д	d
Дека	10^{1}	дк	da
Гекто	10^{2}	г	h
Кило	10^{3}	к	k
Мега	10^{6}	М	M
Гига	10^{9}	Г	G
Тера	10^{12}	Т	T

1. Prefixes; 2. numerical values; 3. abbreviations; 4. Russian; 5. pico; 6. nanno; 7. micro; 8. milli; 9. centi; 10. deci; 11. deca; 12. hecto; 13. kilo; 14. mega; 15. giga; 16. tera. 17. international.

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M. Domshlak

Medical Radiology

Medical radiology (from the Latin radius--ray, and Greek logos--study of) is the science of application of ionizing radiation to medicine (see Ionizing Radiation). Medical radiology combines a number of independent medical disciplines and trends, including: roentgenology (q.v.), medical radiobiology (q.v.), clinical radiology (radiation therapy (see curietherapy, x-ray therapy), x-ray diagnosis (q.v.), tracer diagnosis (q.v.), clinical aspectsand treatment of radiation injuries (see Radiation Sickness), radiation biochemistry and radiation microbiology (see Radiobiology), radiation hygiene (q.v.), the theory and organization of antiradiation protection (q.v.).

Radiology (we mean also medical radiology here) traces its beginning to the time of demonstration of the properties of the new rays by W. K. Roentgen at the Wurzburg Society of Natural Scientists and Physicians (1896), at which time their importance for the diagnosis of disease was immediately determined. Shortly after (1896) the basis of x-ray therapy and radiobiology was laid. With the discovery of radium in 1989 and the elucidation of the biological activity of its radiation the therapeutic utilization of preparations of this radioactive element was begun.

For forty years progress in radiobiology was made chiefly in connection with the demands of radiation therapy. After the discovery of artificial radioactivity and with the production of artificial radioactive agents the limits of radiology were expanded. With the use of radioactive phosphorus (P^{32}) for the treatment of leukoses and polycythemia (1937) and subsequently, radioactive cobalt (Co^{60}), sodium (Na^{24}), iodine (I^{131}), strontium (Sr^{89}, Sr^{90}), yttrium (Y^{90}), gold (Au^{198}) and others new methods of curietherapy appeared, and radioisotopic diagnosis was born. Mass injury to people from the atom bomb explosions in the Japanese cities of Hiroshima and Nagasaki (1945) increased attention and interest in the problem of the biological effect of radiation and gave a particular direction to radiobiology. The significance of radiobiology was further increased with the development of the atomic industry and the utilization of radioactive isotopes and emanations in various branches of the national economy. In turn, the expansion of the technical basis and of knowledge opened up new pathways in radiology. Specifically, this applies to the use of various particle accelerators (see Betatron, Charged Particle Accelerators) and preparations with radioactive isotopes for purposes of treatment and diagnosis. The utilization of new types of radiation (neutron, proton and braking high-energy radiation /bremsstrahlung/, and high-energy electronic radiation) advanced new radiobiological problems and primarily the problem of the relative biological effectiveness of various types of radiation. Problems of radiobiology were expanded even further inconnection with the attainments of cosmonautics and the creation of a new branch of medical science, space medicine.

Two periods can be seen in the development of radiology: the first, which lasted about forty years and is characterized by

the development, technical and methodological mastery of x-ray diagnosis, x-ray and curietherapy, accumulation and systematization of factual material and the development of the theoretical principles in these fields as well as in radiobiology, mainly considering the problems of radiation therapy; the second, later period, distinguished primarily by the extension of the boundaries of the various disciplines comprising radiology which had already been created. This extension is associated with the appearance and utilization of new types of radiation and numerous artificial radioactive isotopes, which either required study from a radiobiological aspect or posed clinical problems, finding progressively greater clinical application. The second period of medical radiology is distinguished by the improvement of the quantitative characteristics of radiation; this applies particularly to the study of the biological effect of radiation on the basis of an accurate dose estimation of the radiation effect as well as to the field of diagnostic and therapeutic utilization of radiation with consideration of the magnitude of the effect and the characteristics of the spatial distribution of radiation in the organs and tissues of man

The development of radiology is being accomplished on the basis of achievements in the field of physics, chemistry, biology, physiology, pathophysiology, biochemistry, microbiology, clinical medicine hygiene. Radiology utilizes factual material, the principles and the methods which these disciplines have at their disposal. At the same time the principles being worked out in the field of radiology and the methods which medical radiology is developing are utilized widely in the various divisions of medical science. Thus, radioisotope analysis has opened up new possibilities for gaining knowledge of the rules and regulations of entrance and distribution of various agents in the body and excretion of them from the body, which has found considerable application in biochemistry, pharmacology and clinical medicine. Neutron activation analysis, autoradiography, and microroentgenography have extended the boundaries of the study of tissue structures. Radiological methods have enriched microbiology and genetics.

The use of ionizing radiation in medicine prior to the October Revolution in Russia developed slowly because of the technical backwardness to which tsarism had doomed the country. At the same time, Russian scientists had, since the first few years of utilization of x-rays and radium emanations, intensively worked out problems of radiology based on the glorious traditions of Russian medical science. Noteworthy studies for finding out various aspects of the effects of the new types of radiation were made by I. R. Tarkhanov, Ye. S. London, T. I. Zhukovskiy, S. G. Zaretskiy, S. V. Gol'dberg, M. L. Gorovits-Vlasova and others in the first few years after the discovery of x-rays (q.v.) and radioactivity (q.v.). These studies, made first at the chairs of the Military Medical Academy and at the Institute of Experimental Medicine, were subsequently developed in other scientific centers of the country. Progress in Russian radiology, made even in the studies of the initial period, was particularly great in the field of finding out the physiological reactions to the radiation effect.

The development of radiology in the USSR was associated with the surmounting of the technical backwardness, the creation and

equipping of radiological centers and a network of specialized institutions in the country after the revolutionary changes.

In the USSR the development of radiology has been assured by State planning, extensive assignation of means and supervision by the Academy of Sciences USSR, Academy of Medical Sciences USSR, the ministries of health of the USSR and the union republics, the Committee of Medical Radiology as well as the influence of scientific roentgenological and radiological societies headed by the All-Union Society.

The development of radiology in the Soviet Union is directed by the scientific and scientific-organizational activity of special scientific research institutions of the USSR, particularly by the Institute of Roentgenology and Radiology in Leningrad (now, the Central Institute of Medical Radiology of the Ministry of Health USSR), founded by a group of scientists headed by M. I. Nemenov (q.v.) in 1918 and integrating within its walls the activity of the greatest physiologists, pathologists, working on problems of radiobiology, as well as scientists in the field of roentgenology.

A great part in the development of radiology is played by the Institute of Roentgenology and Radiology in Moscow, created by P. P. Lazarev (q.v.) in 1924. The work of this institution created the basis for the development of x-ray medical technique in the USSR and is making an essential contribution to progress in x-ray diagnosis, roentgenotherapy and curietherapy. In 1959, the construction of the Institute of Medical Radiology of the Academy of Medical Sciences USSR was begun. Along with these institutions, the Institute of Radiation Hygiene (Leningrad), the Institute of Labor Hygiene and Occupational Diseases (Moscow) the Khar'kov Institute of Medical Radiology, the Kiev Institute imeni A. A. Bogomolets, the Ukrainian Roentgeno-Radiological and Oncological Institute, chairs of roentgenology and radiology of institutes for the advanced training of physicians and medical institutes are working on the solution of radiological problems. The development of radiology in the USSR is based to a considerable degree also on research and organizational work of oncological institutions, particularly the Institute of Oncology of the Academy of Medical Sciences (Leningrad) and the State Oncological Institute imeni P. A. Gertsen (Moscow).

The achievements of radiology in the USSR are associated with the work of many eminent men of Soviet roentgenology, radiobiology and other radiation disciplines, who have made an essential contribution to this field of medical science as well as to medical practice. In the field of clinical radiology the following representatives of Russian and Soviet radiology have been pioneers in a number of divisions and have led various trends or founded chairs: S. R. Frenkel' (q.v.), who founded the chair of roentgenology of the First Moscow Medical Institute and who contributed to the development of radiation therapy in oncology; B. A. Arkhangel'skiy (q.v.), who developed the use of radiation in obstetrics and gynecology; F. S. Grosman, who left his mark on the field of development of curietherapy; L. I. Gol'st (q.v.), the founder of the chair of roentgenology of the Central Institute of Advanced Training of Physicians; O. O. Den, pioneer of the Leningrad school of roentgenologists;

M. Ye. Shtern (Saratov), well known specifically for his monograph on pulmonary echinococcosis; the oldest Moscow roentgenologists A. V. Ayzenshteyn and A. A. Tsevtlin, the founders of chairs of roentgenology at the Second and Third Moscow medical institutes; Ya. G. Dillon, awarded the State Prize of the USSR for the method of roentgenotherapy of cancer of the lung which he proposed; M. I. Karlin, one of the first x-ray therapists; A. Ye. Prozorov (q.v.), well known for investigations in the field of x-ray diagnosis of tuberculosis; L. D. Podlyashuk, the author of radiobiological studies and a textbook on x-ray therapy; G. I. Kharmandar'yan, who founded the Khar'kov Institute of Roentgenology and Radiology (now, the Institute of Medical Radiology) and who united a number of eminent representatives of radiology (among them: I. G. Shlifer (q.v.), B. K. Rozenshteyg, A. L. Khalinskiy and others); N. N. Isachenko, founder of the chair of roentgenology of the Odessa Medical Institute; I. M. Gol'dshteyn and D. S. Lindenbraten, who made contributions to clinical radiology and radiobiology. Among the leading representatives of clinical radiology, who continued the work of developing this discipline was S. A. Reynberg (q.v.), founder of the first Soviet chair in the Leningrad State Institute for Specialization and Advanced Training of Physicians and of a school of roentgenologists, the author of well-known textbooks on roentgenology; D. G. Rokhlin (q.v.), who headed the chair of the First Leningrad Medical Insitute, the creator of a roentgeno-anthropological trend; I. L. Tager (q.v.), the author of original studies, particularly in the field of gastrointestinal pathology, director of the chair at the Central Institute for Advanced Training of Physicians; V. A. Fanardzhyan (q.v.), director of the Armenian Institute of Roentgenology and Radiology; G. A. Zedgenidze (q.v.), author of a number of monographs; Yu. N. Sokolov, director of chair at Central Institute for the Advanced Training of Physicians, author of original investigations; S. A Pokrovskiy, author of a monograph on bone lesions; N. A. Panov, who made a contribution to the development of roentgenology in pediatrics; K. V. Pomel'tsov, eminent phthisiatric roentgenologist; A. V. Kozlova, well known specialist in the field of curietherapy; V. A. D'yachenko, who heads the chair of the Second Moscow Medical Institute; I. A. Shekhter, director of the chair of the Moscow Medical Stomatological Institute; G.F. Nazarishvili--leading roentgenologist of Georgia, director of the Georgian Institute of Roentgenology and Radiology; A.A. Lemberg, who heads the chair of the Khar'kov Institute for the Advanced Training of Physicians; I. V. Lagunova, director of the Institute of Roentgenology and Radiology RSFSR, author of monographs on bone pathology. One of the oldest specialists in radiology is head of the chair of roentgenology of the Stanislav Medical Institute, M. Y. Afanas'yev. Ye. D. Dubovyy, who heads the chair of roentgenology and radiology of the Odessa Medical Institute is the author of monographs on radiation therapy and the use of radioactive isotopes; M. B. Kopylov, M. N. Al'tgauzen, Ya. I. Geynisman are well known for studies in the field of neuroroentgenology; A. I. Dombrovskiy heads the chair of roentgenology of Rostov Medical Institute. Eminent roentgenologists who are at the heads of chairs, professors in

chairs and directors of scientific research institutions are B. M. Varshavskiy, R. Ya. Gasul', V. G. Ginzburg, Ya. I. Geynisman, M. I. Gol'dshteyn, A. V. Grigor'yeva, V. V. Zodiyev, A. V. Kantin, N.S. Kosinskaya, A. P. Lazareva, L. D. Lindenbraten, M. Ye. Manikov, B. G. Mikhaylovskiy, M. M. Mikhaylov, V. K. Modestov, K. P. Molokanov, V. I. Petrov, L. S. Rozenshtraukh, A. I. Ruderman, M. Kh. Fayzulin, V. Ya. Fridkin, B. A. Tsybul'skiy, K. N. Chochia, B. K. Shtern, V. N. Shtern, A. A. Shtuss, I. M. Yakhnich and many others.

A considerable part in the development of the physical engineering trend in radiology has been played by K. K. Aglintsev, A. V. Bibergal', V. V. Bochkarev, V. A. Vitka, N. G. Gusev, V. V. Dmokhovskiy, N. V. Dobrov, G. A. Zhegalkin, B. M. Isayev, A. N. Krongaus, U. Ya. Margulis, M. S. Ovoshchnikov, N. D. Perumova, V. A. Petrov, M. F. Popov, I. V. Poroykov, V. I. Rakov, F. I. Solov'yev, S. M. Stepanov, E. Ye. Troitskiy, A. I. Tkhorzhevskiy, M. I. Teumin, N. Ye. Uspenskiy, F. N. Kharadzha, V. G. Khrushchev, Ya. L. Shekhtman, S. I. Shirokov, V. K. Shmelev and others. Many of them are the authors of special monographs and textbooks.

Radiobiological study, the pioneers in which in the Soviet Union have been mentioned above, is being developed in a number of scientific enters of the country. Among them, an appreciable contribution has been made by the biophysical scientific research institutions of the Academy of Sciences USSR and the Academy of Medical Sciences USSR. The scientific groups of these institutions, headed by A. V. Lebedinskiy (q.v.), active member of the Academy of Medical Sciences USSR, and G. M. Frank, Corresponding member of the Academy of Sciences USSR, are conducting investigations in various fields of radiobiology (biochemical, physicochemical, physiological, microbiological, pathological and others) under the direction of V. S. Babalukha, P. D. Gorizontov (q.v.), E. Ya. Grayevskiy, N. D. Demin, D. I. Zakutinskiy, N. N. Klemparskaya, N. A. Krayevskiy (q.v.), A. M. Kusin, Yu. I. Moskalev, I. A. Pigalev, V. A. Sanotskiy (q.v.), B. N. Tarusov (q.v.), N. I. Shapiro and many others. Considerable work along these lines has been done in the Central Institute of Medical Radiology by S. N. Aleksandrov, Ye. I. Bakin, P. N. Kiselev, S. Ye. Manoylov, G. S. Strelin and their coworkers. Important studies are also being made by a group of Ukrainian institutes, in which a notable part is being played by the activity of R. Ye. Kavetskiy (q.v.), A. A. Gorodetskiy, S. N. Ledanov and their groups.

The microbiological trend in radiology is represented by V. L. Troitskiy (q.v.) and a group of his coworkers at the Central Institute of Microbiology and Epidemiology of the Academy of Medical Sciences USSR, M. N. Meysel' and others. The studies of M. O. Raushenbakh and his laboratory, the biochemical studies of S. Ye. Severin, D. E. Grodzenskiy, and the radiological-morphological work of B. N. Mogil'nitskiy (q.v.) and his coworkers, done at the Moscow Institute of Roentgenology and Radiology in the 1920's-1940's, the roentgenoanatomic studies of M. G. Prives, A. S. Zolotukhin, P. N. Mazayev, M. I. Santotskiy, the radiobiological work of S. A. Nikitin, S. N. Ardashnikov, V. Ya. Aleksandrov, I. P. Mishchenko and many others are well known.

The progress of radiology in foreign countries is associated with the scientific research activity of a number of authoritative institutions. Among them is Radiumhemmet, an institute organized in 1909 in Stockholm (Sweden) by H. Forsel (q.v.) and which was under his direction for a long time. Radiumhemmet deserves the credit for working out many trends, including principles and organizational practice of radiology in the related fields of oncology (E. Berven, Heymann and others). In this institution also the principles of the biophysical trend were laid down and afterwards developed considerably through the activity of R. Sievert and his coworkers.

At the Institut de Radium of Paris University, founded by M. Curie-Sklodowska (q.v.) and C. Regaud in 1914, a section of clinical radiology, radiophysiology and radiopathology has been created, well known for its contribution to these branches of radiology. The studies of Regaud and his school (Lacassagne (q.v.), Latarjet, H. Coutard, Baclesse) were of first importance in the development of radiobiology, x-ray therapy and curietherapy. The Institut G. Roussy (q.v.) in Paris, which is a clinical and therapeutic center in the field of oncology, deserves mention also.

At this Institute considerable work is being done on radiation therapy (S. Laborde and M. Tubiana and others).

The Cancer Center in London (Chester Betty Research Institute, Royal Cancer Hospital) is known for its contribution to medical physics, made by Mayneord (q.v.) and his coworkers, and for the work of Lederman and Smithers. The radiotherapeutic research center of Hammersmith Hospital in London is the institution with which the investigations of L. H. Gray are associated. In the Manchester radium institute (Holt Radium Institute) a series of studies on the physical basis of radiation therapy has been made for many years under the direction of R. Paterson. The Manchester dosage system in curietherapy and the method of irradiation with the utilization of high-energy braking radiation created here have become well known. A trend which was developed at the Manchester Institute and the London Cancer Center led to the formation of a new specialty--medical physics--as the result of the activity of Mayneord, Paterson and others. In Westminster Hospital (London) S. Cade and others made a great contribution to the development of radiosurgery. In Harwell Atomic Center studies are being made on radiation genetics, headed by Russell.

The New York Memorial Hospital (United States) has a radiation therapy center. At the National Cancer Institute in Bethesda and the Oak Ridge National Laboratory studies are being made in the field of radiobiology (in these studies the leading part is played by A. Hollaender); work is being done on telegammatherapy technique, and other investigations are being made. Considerable work is being done by the Brookhaven National Laboratory, where, specifically, physical, chemical, pharmacological and clinical approaches are being worked out to neutron capture therapy of cancer. At the Donner Laboratory in Berkeley (California) a group of investigators (Tobias, J. Lawrence and others) is working in the field of radiobiology and experimental radiation therapy. Here, studies

with thin proton beams with energies of hundreds of millions of electron volts attract attention; by means of these beams a strictly localized selective effect is exerted on very small areas of a deeply situated organ. In the department of zoology of the University of Indiana (Bloomington) H. J. Muller is making studies on radiation genetics. Considerable work on radiology is being conducted also at the Sloan-Kettering Institute at the Cancer Hospital of the Rockefeller Institute in New York.

Among the radiological scientific institutions of European countries note should be made of the Instituto Nazionale per lo Studio e la Cura dei Tumori (Italy), where the well-known roentgenologist, Perussia, works; the Institut du Cancer in Louvain (Belgium), directed by Maisin; the Radiologisches Institut der Universität Freiburg (FRG), which is now carrying out a program of radiobiological studies (H. L. Langendorf). One of the centers of radiology is the Max Planck Institut für Biophysik in Frankfurt-on-Main, well known for the investigations of B. Rajewsky and the group of scientists under him.

An organization which bears the name of one of the founders of radiology, Antoine Béclère, (q.v.), the so-called Centre Antoine Béclère, in Paris is occupied with problems of cultural relations between the radiologists of the world.

In the USSR problems of radiology are regularly discussed in the special journal Meditsinskaya Radiologiya /Medical Radiology/ (has been in existence since 1956), on the pages of Vestnik Rentgenologii i Radiologii /Herald of Roentgenology and Radiology/ (has been in existence since 1920), Radiologiya-Diagnostika /Radiology-Diagnosis/ and Radiobiologiya-Radioterapiya /Radiobiology-Radiotherapy/ (both of the last two journals are published in Russian and German.

Some problems of radiology are discussed on the pages of general medical journals, particularly in the journal Voprosy Onkologii /Problems of Oncology/. In the journal Radiobiologiya /Radiobiology/, published by the Academy of Sciences USSR, problems are represented which are in fields related to medical radiology.

Abroad, problems of radiology are discussed chiefly in the journals Acta Radiologica (organ of the radiology societies of Norway and Sweden, Denmark, and Finland), The International Journal of Applied Radiation and Isotopes (published by Pergamon Press), Archives of Environmental Health organ of the American Academy of Occupational Hygiene, an American Medical Association publication on prophylactic medicine, occupational hygiene and space medicine), Excerpta Medica (international journal of abstracts; section XIV is Radiology), Fortschritte auf dem Gebiete der Röntgenstrahlen und der Nuclearmedizin (Diagnostik, Physik, Biologie, Therapie) (Organ of the Society of Roentgenologists of the FRG), Health Physics (Organ of the Society of Medical Physics), Journal Belge de Radiologie (Organ of the Belgian Radiological Society, also publishes the work of the Netherlands Radiological Society), Journal de Radiologie, d'Electrologie et de Medecine Nucleaire (organ of the French Society of Medical Electro-radiology and its affiliates), International Journal of Radiation Biology and Related Studies in Physics, Chemistry and Medicine (published

by Taylor and Francis Ltd), Radiation Research (organ of the Society of Radiation Research, published by the Academic Press, New York and London), Radiology (journal of clinical radiology and related disciplines, organ of the North American Radiological Society), The American Journal of Roentgenology, Radium Therapy and Nuclear Medicine (organ of the American societies of roentgenology and radiology), Strahlentherapie (archives of clinical and experimental radiation therapy--x-rays, radium and radioactive isotopes, light; simultaneously, the journal discusses problems of cancer control; the organ of the Roentgenological Society, Society of Phototherapy and Optics as well as the Society of Oncology), The British Journal of Radiology (founded in 1896 ; organ of the British Institute of Radiology and the X-Ray Society), Zentralblatt für die gesamte Radiologie (journal of abstracts of the Society of Roentgenologists of the FRG), Radiologia Clinica (International Radiological Review Journal, organ of the Swiss Roentgenological Society), Radiologia Austriaca (Austria).

There are annuals written on problems of radiology: Year-Book of Radiology (has been published since 1900 by the Year Book Publishers Inc., Chicago), Ergebnisse der medizinischen Strahlenforschung (vols I-VII, 1925-1936, published by Thieme, Lepizig), Röntgendiagnostik, Ergebnisse 1952-1956 (published by Thieme, Stuttgart, 1957), Strahlenbiologie, Strahlentherapie, Nuklearmedizin und Krebsforschung, Ergebnisse, 1952-1958 (published by Thieme, Stuttgart, 1959).

A number of international and Soviet congresses, conferences and meetings have been on problems of medical radiology.

In 1955 and 1958, the first and second international conferences on peaceful uses of atomic energy were held in Geneva. Since 1952, periodically, international symposia are collected on problems of the biological effect of ionizing radiation. The international conferences on radiology are also conducted by the International Atomic Energy Agency and the World Health Organization (WHO). In the United Nations Organization in 1956 a Commission for the Study of the Effect of Atomic Radiation was created, in whose work the delegation of the USSR, which insists on prohibiting the testing of nuclear weapons on the basis of the data of radiobiology, participates actively. At the Eighth International Congress of Roentgenologists and Radiologists (1956) the International Society of Roentgenologists was instituted. Aside from this, the International Society on Radiation Research functions (formerly, the Organization of International Radiobiological Conferences). Problems of Radiological protection are integrated by the International Commission on Radiological Protection, ICRP). In addition, there is an International Commission on Radiological Units (ICRU).

In 1954, in Moscow, the Academy of Sciences USSR held a meeting on problems of the study of the effect of ionizing radiation on the animal organism. In 1955, a meeting of the Academy of Sciences USSR was held on the peaceful uses of atomic energy, at which reports were given on problems of radiology at the section of biological sciences. At the first All-Union Conference on Medical Radiology (Moscow, 1956) an analysis was made of the problems of experimental radiology, radiation

hygiene and dosimetry, the clinical aspects and therapy of radiation sickness. In 1956, at the All-Union Conference of Active Public Health Workers in Moscow there was a section on radiological problems. In 1957 (Moscow), the All-Union Technical Scientific Conference on Application of Radioactive and Stable Isotopes and Emanations to the National Economy and Science was held (organised by the Academy of Sciences USSR and by Glavatom /Main Atomic Energy Administration/), at which reports were heard on problems of radiology. At the session of the Academy of Medical Sciences USSR (Moscow, 1957), a special meeting was held on "radiation injury." In 1957, an intercollegiate conference was held on the problem of the biochemical and biophysical bases of the biological effect of radiation. In 1959, at the Conference on Uses of Atomic Energy for Peaceful Purposes (Tashkent) reports were given on problems of radiology. In 1960, in Riga a conference was held on the peaceful uses of radioactive isotopes and nuclear radiation. In 1961, the First All-Russian Congress of Roentgenologists and Radiologists was held (Kuybyshev).

Conferences were held on problems of application of radioactive isotopes to medicine (Moscow, 1949), therapeutic application of radioactive cobalt (Leningrad, 1952), radioactive phosphorus treatment of erythremia and leukosis patients (Leningrad, 1953), the specificity of the body's reactions to the effect of injuries caused by the action of ionizing radiation (Moscow, 1956), the pathogenesis of the clinical aspects, therapy and prophylaxis of radiation sickness (Leningrad, 1957). A special conference was devoted to the results of scientific studies in the field of radiobiology (Leningrad, 1959). A special meeting in 1960 (Moscow) was on the problem of clinical radiology.

M. Domshlak

Military Radiology is an educational and a scientific subject, which studies the physical and biological principles of injuries caused by the injurious radiological factors in atomic (nuclear) weapons. Military radiology was born simultaneously with the appearance of atomic weapons as armament in certain countries (q.v.).

Military radiology is based in its development on the achievements of general and medical peacetime radiology, particularly, on the attainments of radiobiology (q.v.), and independently works out the problems specific for wartime conditions experimentally, namely: 1) the biophysical rules and regulations of development of different types of radiological combat injuries (q.v.); 2) individual and group measures of antiradiation protection (q.v.); 3) quantitative determination of the probable radiation injuries with respect to the degree of their severity in the focus of atomic attack with different conditions and modes of utilization of the atomic weapons (depending on the type of nuclear explosion, composition of the radioactive agents used for combat, the power of the nuclear weaponry, the degree of radioactive contamination of the locality, the disposition of the troops, etc.); 4) the distinctive nature of the course of the radiation injuries of combat (see Radiation Sickness); 5) the characteristics of combined

injuries with the participation of the injurious radiation factor (see Combined Combat Injuries); 6. principles of early diagnosis, including evaluation of dosimetric (q.v.) data and radiometric (q.v.) data; 7) treatment of people injured by penetrating radiation and radioactive agents in stages: sorting at clearing stations and sorting by type of evacuation transport (see Medical Sorting); the volume, means and methods of comprehensive therapy; tentative treatment time and prognosis.

The data of military radiology are widely used by many branches of military medicine, for example, by military pathology, military field therapy and surgery, organisation and tactics of the military medical service, and others (see Military Medicine). Problems of military medicine are discussed on the pages of the Voyenno-Meditsinskiy Zhurnal /Military Medical Journal/. Soviet physicians are trained in matters of military radiology at chairs of institutes for the advanced training of physicians, simultaneously with advanced training in the main specialty and as applied to it.

I. Ivanov

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Radar

Radar (from the Latin radiare, to emit, and locatio, location) is the detection of various objects (targets) and the determination of their location on dry land, in the water and in the air by means of radio waves.

The radar effect is based on the reflection of radio waves from obstacles in their path. The waves are emitted and the returning (reflected or scattered) signal is received by a special technical apparatus, the so-called radar apparatus or radar station. The latter is equipped with a directional antenna, which emits and receives signals in a limited area, which makes it possible to determine the angular coordinates of the target. At the same time, the period elapsing from the moment of emission of the pulse until its return to its starting point gives an idea of the distance to the target. These data, taken together, permit determining the location of the target. The target found by radar is shown in the form of a light signal on the screen. The existence of regularly rotating antennas at radar stations makes it possible, by means of radio waves, successively to "feel out" the entire surrounding area in search of targets which might appear within it as well as to determine their speeds and directions. All this assures an active radar search, which differs from an optical (visual) search in its independence of the degree of visibility (the same in fog, at night, in smoke curtains, etc.) and its immeasurably greater "range."

These possibilities of the radar method have been responsible primarily to military affairs; the first radar stations (1939) were utilized for detection of airplanes in the air defense system (q.v.). At the present time, the significance of radar has increased for these purposes. In addition, it is used for controlling combat in the air by means of the so-called direction stations (which make it possible to direct one's own airplanes against the enemy's airplanes), for homing artillery, including antiaircraft, on a target, for guiding rockets, for bombing and others.

Radar is also of great scientific and national economic significance. It is used in civil aviation as a means of providing flight safety and for guiding airplanes under reduced visibility conditions; in meteorology, for receiving the signals of radio-sondes and sounding balloons; in radio astronomy for studying radio waves reflected from celestial bodies.

Work on radar instruments requires concentrated attention, considerable visual strain, and adequate adaptive capacities, quick and accurate reactions. Finding the target sought on the screen of an electron-beam tube and, most important, identification of it, determination of its nature and location are not uncommonly connected with considerable difficulties, particularly when the image is of low intensity or of a diffuse nature. In a combat situation additional difficulties may be caused by the radar interference created by the enemy. In connection with this, in operators working directly at the

screen and close to it, fatigue occurs after a certain period which is fraught with the danger of errors.

From the hygienic viewpoint the hazards with which the work of the operators and technicians may be connected in the operation of radar stations are also of some importance. The latter arise (chiefly during repair of the apparatus) as the result of the emission of a superhigh frequency pulsating electromagnetic field by the antennas and oscillator units (capable, when of the appropriate power, of causing heating up of tissues and affecting the functional state of the central nervous system), as well as from x-radiation coming from the oscillator tubes. However, such effects are not observed during the course of operation of the stations in good order; the superhigh frequency field and x-radiation are practically absent on the premises of the station, which is assured by the presence of screens around all the radar apparatus units. Only when the apparatus is turned on after the removal of the protective coverings are such effects possible (chiefly, on the technical personnel occupied in repair). In addition, persons who are outside the station in the field created by the antenna may be exposed to these effects. In connection with this, suitable safety measures should be observed by the radar station personnel (see Clothing (protective), Antiradiation Protection)

It is also necessary to see that suitable temperature conditions are maintained on the premises of the station, not permitting overheating of the air because of the propagation of the heat formed in the operating apparatus through convection and radiation. It is equally important to see that the normal chemical composition of the air is maintained, keeping in mind the possible contamination of the air with ozone, oxides of nitrogen (from the operation of spark dischargers) and products of activity of the body; this determines the importance of good ventilation in the radar station premises. Finally, the noise occurring in the operating apparatus and in ventilation apparatus can create a certain strain on the organism.

By virtue of these facts, among radio mechanic troops and in other units which use radar apparatus as well as in the corresponding civilian installations, medical checking of the state of health of the personnel, of observance of the working and resting conditions established for the personnel and hygienic control of the working conditions at radar stations (the microclimate, chemical composition of the air, radiation levels, etc.) acquire special importance. It is also necessary appropriately to select candidates for work at radar stations, considering the characteristics of this type of work. See also Work, Electromagnetic Field.

Clinical Radiometer

The clinical radiometer is a portable apparatus designed for determining the circulation time by the tracer method (see Isotopes, radioactive). The clinical radiometer can be used for determination of the outlines of areas in which radioactive isotopes are located in the body (for example, the thyroid gland saturated with radioactive I^{131}) and on the surfaces of objects.

The sensing element of the instrument is a scintillation counter consisting of an NaI monocrystal activated by thallium (Tl) and an FEU-25 or FEU-35 photomultiplier. The light flashes in the crystal caused by absorption of gamma quanta are converted into electric pulses by the multiplier which after amplification and shaping go to the integrator, which converts them into direct current, proportional to the pulse repetition rate, which, in the final analysis, is proportional to the intensity of gamma-radiation falling on the crystal. A microammeter and an ink-recorder are connected up to the outlet of the integrator.

For the purpose of assuring directional sensitivity of the counter the crystal is placed in a cylindrical lead shield--the collimator--with an opening about 2 sq. cm. in area along its axis. In addition, there is an electronic apparatus in the circuit of apparatus which provides a nonlinear relationship (to a degree higher than first degree) between the instrument readings and the intensity of the gamma-radiation falling on the crystal. This makes it possible more distinctly to determine the moment the radioactive isotope carried by the blood stream approaches the counter.

The instrument (see Figure) consists of an outlying detector (in which the crystal, photomultiplier, collimator, voltage divider and cathode follower are located) and a control panel, housed in a metal suitcase. The detector is connected to the panel by a flexible cable. On the front (top) of the panel are an indicator, recorder, controls and jacks for connecting the instrument to the line and for connection of an injection timer button set on the head of a syringe. The instrument has a timer which marks time at one-second intervals.

For successful measurement of the circulation time the detector is placed on one of the extremities with its sensing end as near as possible to the large blood vessels; the radioactive isotope is injected into the vein of the opposite extremity; the distance between the detector and the injection site of the solution should be as great as possible; the activity of the Na^{24} isotope injected in the form of NaCl should amount to 10-50 microcuries. The quantity of solution should not exceed 0.2-0.3 cc. The solution is injected intravenously in as short a time as possible. Immediately after the injection, the syringe should be removed from the detector.

Aside from the quantity of the Na^{24} isotope needed for the measurement, there should be no radioactive sources in the room in which the observation is being made. All work in the preparation of the solution should be conducted in a special room, as far as possible

from the place of the measurement. Observance of the conditions mentioned above in combination with proper adjustment of the instrument (according to instructions) makes it possible to determine quite precisely the time between the injection of the isotope into the body (the beginning of the thickened /probably "flattened" intended/ portion of the curve) and its passage through the blood vessels under the detector (maximum of the peak on the curve). In a number of cases it is possible to observe the passage of the isotope under the detector twice; however, the second peak is very indistinct, as a rule.

Figure

[Photograph not suitable for reproduction; available in source.]

K. Kalugin

Radiometric Instruments

Radiometric instruments are apparatuses for measuring the activity of natural and artificial sources of radiation. Radiometric instruments are used for different physical investigations, for prospecting for minerals, checking on technical processes in industry and others. Radiometric instruments are of great importance for biology and medicine, where they are used for scientific research, and they permit medical monitoring of working conditions and checking on the health of the personnel of institutions associated with the use of radioactive agents.

Any radiometric instrument consists of two main parts--a radiation detector and a measuring instrument which makes it possible to measure or record the effect caused by radiation.

In accordance with their functions, radiometric instruments are divided into laboratory instruments for measuring the activity of sources of radiation, field radiometers for seeking out minerals, signal radiometers of the technical dosimetric type, instruments for measuring fluxes of ionizing radiation with the aim of determining radioactive contamination, and others. According to the type of radiation the instrument is designed to record, alpha-, beta- and gamma-radiometers as well as instruments for measuring a neutron flux are distinguished. According to their operating conditions, pulsating and integrating radiometric instruments are distinguished. At the outlet of the instrument designed for pulse work, a series of pulses arises under the influence of radiation each of which corresponds to the passage of a nuclear particle. Integrating instruments permit measuring the average effect caused by simultaneous passage of a multitude of particles.

In accordance with the nature of the physical process occurring in the detector under the influence of radiation, radiometric instruments are divided into ionization, scintillation (luminescent), calorimetric, radiographic and others.

Ionization and scintillation radiometric instruments have become most common in practical radiometry. In the ionization instruments a gas-discharge counter or ionization chamber serves as the detector. By means of counters the activity of sources of beta-radiation is measured. The ion chambers serve for measuring the activity of the alpha-radiation sources. In order to determine the activity of the preparation it is necessary to count the number of disintegrations occurring in it per unit time. Since a strictly defined number of beta-particles is emitted for a single disintegration, the activity of the preparation can be determined by calculating the number of particles emitted per unit time by means of the counter. For the purpose of measuring the number of beta-particles apparatuses with end-type counters are used, as a rule; they possess better geometry and have thin inlets. This makes it possible to record soft radiation, which, in turn, provides better accuracy.

For the work with counters laboratory and field counters are used. In laboratory practice the B-2 counter radiometer is widely used; it consists of a pulse amplifier, high-voltage rectifier and a scaler with a mechanical annunciator (Fig. 1). For the purpose of shielding against external influences the counter is placed in a protective lead housing. Conversion from the number of pulses measured to the number of beta-particles emitted by the preparation and then to the activity of the preparation is carried out by the introduction of a number of corrective factors. The B-2 unit is used for accurate measurement of the activity of radiation sources.

For the purpose of determining surface contamination with alpha-, beta- and gamma-active substances under conditions of fixed installations the universal "Tiss" radiometer is used (Fig. 2). It makes it possible to determine very slight contamination (constituting the degree permissible). The contamination is determined by the number of pulses per unit time by means of thin-walled gas discharge counters. The instrument is constructed in the form of a table-model control panel with a set of outlying detectors for alpha- and beta-radiation.

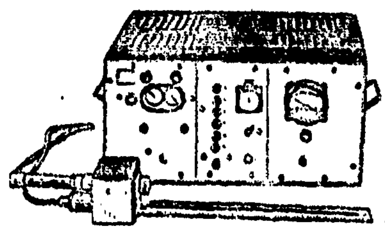

Fig. 1. B-2 Apparatus

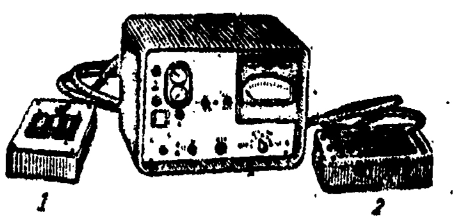

Fig. 2. Universal "Tiss" Radiometer. 1. detector for measuring contamination with beta-, gamma-active substances; 2. detector for measuring contamination with alpha-active agents.

There are radiometric instruments for detecting radioactive contamination under field conditions. In this group is the beta-gamma DP-11B radiometer. It can also be used for detecting radioactive substances in water and other fluids. The instrument consists of a portable control panel and a probe with a gas discharge counter. Radiometers of this type have a low degree of accuracy (±50 percent) and require preliminary calibration.

More sensitive are the scintillation radiometers, in which the capacities of a number of substances--phosphors--for emitting part of the energy expended by the nuclear particle in exciting and ionizing molecules in the form of light are used. The light flashes in the phosphor are converted into pulses of electric current, strong enough to be recorded, by means of a photomultiplier. Scintillation radiometric instruments are used for measuring alpha- and beta-radiation. Thus, for example, a scintillation attachment for measurement of alpha-radiation is included in the set of the B-2 apparatus. Included in the set of the "Tiss" instrument is also a scintillation alpha-radiometer.

In medicine, biochemistry and biophysics chiefly ionization and scintillation radiometric instruments are used. By means of them and through the tracer method a study is made of various physiological functions of the body normally and in pathology (nature of photosynthetic, respiratory, metabolic and protein reactions, renewal rate of tissues, circulation time, etc) (see Isotopes), and various diseases are diagnosed (see Radioisotopic Diagnosis).

Medical monitoring is an important field of application of radiometric instruments. Thus, for example, measurement of the specific activities of biological media, water and food products is accomplished, as a rule, by means of the B-2 radiometer. The absence of contamination on the skin, clothing, effective surfaces and industrial premises is checked with the "Tiss" radiometer. The content of radioactive gases and aerosols in the air is measured with radiometers which have ionization chambers and beta-counters. Scintillation apparatuses permit measuring the external radiation from a person after the entrance of gamma-emitters and hard beta-radiation into the body. The general view of this apparatus is shown in Fig. 3. There are radiometers which permit determining the content of radioactive agents in the body by the activity of the exhaled air. Thus, by the radon content in the exhaled air it is possible to determine the radium contained in the body. The great variety of practical problems has been responsible for the appearance of medical and clinical radiometers of the most varied types in recent years.

See also Dosimetry, Radiometry.

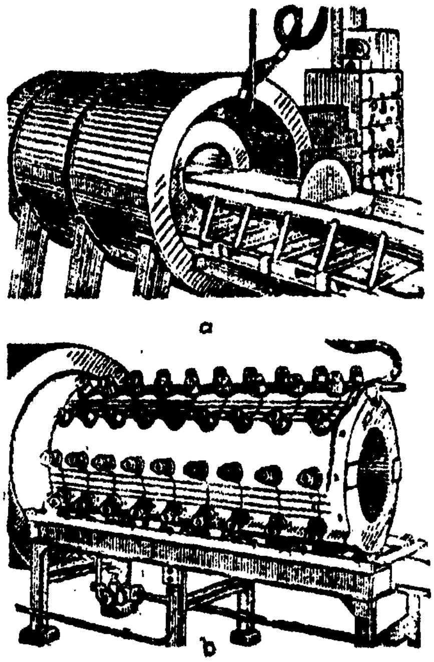

Fig. 3. Large Counter with Liquid Scintillator for Measurement of Gamma-Activity of the Human Body: a--general appearance; b--counter taken out of protective housing.

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